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FOR HYDROFOILS

by

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DESIGN OPTIMIZATION OF WATERJET PROPULSION SYSTEMS FOR HYDROFOILS

by

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ABSTRACT

A generalized waterjet propulsion system in a sub-cavitating hydrofoil craft is considered for design and performance estimation. Independent system parameters of jet velocity ratio, inlet velocity ratio, and nacelle inlet diameter to maximum diameter ratio are varied to search for the optimum system. The optimum system is defined as the minimum total propulsion system weight. The optimization scheme utilizes a directed search without the calculation of derivatives, and was chosen for its simplicity, versatility, and rapidity. The ducting system is divided into components for head loss calculations. For a given design, total head losses in the duct are computed by means of experimental data and empirical equations, enabling pump, reduction gear, and prime mover design to be completed. Results for a sample craft are included which indicate that hydrofoils should be designed about the gas turbine, due to the discrete power levels that are available. Suboptimizing the nacelle design may lead to an overall less optimum system design. A general lack of information was noted on nacelle, cascade corner, and three dimensional diffuser design and performance prediction. A FORTRAN computer listing and flow charts are included.

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List of Symbols

A - Cross sectional area of duct, square foot

c - Strut chord, foot

C - Loss coefficient factor for diffuser, based on equivalent angle

C_1, C_2 - Constants

C_d - Nacelle drag coefficient, based on wetted surface area

C_{d_s} - Strut drag coefficient, based on planform area

$C_{d_{sp}}$ - Spray drag coefficient, based on planform area

C_{f_s} - Schoenherr friction coefficient

D - Drag, pound force

D_e - Mean hydraulic diameter, foot

D_i - Inlet diameter, foot

D_j - Jet diameter, foot

D_m - Nacelle maximum external diameter, foot

D_t - Nozzle throat diameter, foot

f - Moody friction factor

g - Acceleration of gravity, foot per second squared

h_a - Atmospheric pressure head, foot

h_{elev} - Elevation head, foot

h_i - Total head loss to pump inlet, foot

h_n - Nozzle head loss, foot

h_t - Total duct head loss, foot, $h_t = h_i + h_n$

h_v - Vapor pressure head, foot

K_e	- Expansion loss coefficient of diffuser
K_t	- Total loss coefficient
K_1, K_2	- Loss coefficients at different Reynold's numbers
L	- Lift, pound mass
L_j	- Nozzle length, foot
L_n	- Nacelle length, foot
Ln	- Natural logarithm
NPSH	- Net positive suction head, foot
p	- Static pressure, pound force per square foot
P	- Wetted perimeter, foot
Q	- Volume flow rate, cubic foot per second
r_i	- Inside bend radius, foot
r_{i_a}	- Inside subdivided elbow radius, foot
r_o	- Outside bend radius, foot
r_{o_a}	- Outside subdivided elbow radius, foot
R	- Radius of bend centerline, foot
Re	- Reynolds number
RO	- Internal duct radius, foot
RPM	- Revolution per minute
SFC	- Specific fuel consumption, pound fuel per horsepower hour
SHP	- Shaft horsepower
t	- Strut thickness, foot
T	- Thrust, pound force
T_v	- Thrust vertical component, pound force

V - Average water velocity, foot per second

V_i - Inlet velocity, foot per second

V_j - Jet velocity, foot per second

V_o - Craft velocity, foot per second

W - Weight, pound mass

z - Elevation above reference level

α - Numerical factor in bend loss coefficient

β - Optimum nozzle depression angle, degree

θ - Bend angle, measured from horizontal, degree

2θ - Equivalent angle of diffuser, degree

λ - Factor in mixing loss coefficient of junction

ρ - Water density, pound force second squared per foot to the fourth

σ - Thoma's cavitation index

ϕ - Angle of junction, degree

χ - Loss coefficient correction for Reynold's number

ψ - Nozzle angle, degree

CHAPTER 1 - INTRODUCTION

The use of waterjets for the propulsion of marine vehicles at conventional ship speeds has not been considered comparable to that of propellers. Although the concept is quite old, the disadvantages of waterjets have not been overcome and the advantages not realized. At the speeds considered, the low system efficiency, large system weight and relatively sophisticated technology required were sufficient to virtually exclude waterjets from competition with propellers. With the advent of high speed craft however, this means of propulsion is receiving a renewed interest as a practicable system. Among the possible advantages that may be realized are (refs. 1,2):

a. Reduced noise and vibration

b. Fewer system components

c. Elimination of underwater appendages

d. Elimination of complex transmission machinery

e. Limited draft applications

f. Simplification of steering devices

For hydrofoil craft, the waterjet looks particularly attractive. It neatly avoids the problem of conventional propellers in power transmission (refs. 3,4). For this reason, waterjet propulsion development to-date has been primarily concerned with hydrofoil applications. In addition, new concepts in ships, such as surface effect

ships and captured air bubble craft, are now including consideration of waterjets as a possible propulsion system. With this surge of interest, the need to go beyond the practical "Will it work?" engineering design method has become paramount. The question has become, "What is the best waterjet propulsion system for the craft under consideration?". Answering this question requires a strictly formulated methodology previously not required in make-it-work technological levels. No longer is it satisfactory to find some point, any point, above the minimum acceptable level. The scope has been enlarged to pinpointing the optimum within the entire domain of feasibility. The immensity of this task coupled with its relative lack of need has hampered the implementation of a methodology. Hydrofoils have demonstrated the need, while computers provide the invaluable aid for the required computations; therefore, an optimization methodology has been developed.

CHAPTER 2 - DESIGN METHODOLOGY

To initialize the design method, a clear definition of the desired objective must be given. In the present instance, the definition is the answer to the question, "What is meant by an optimal waterjet propulsion system?". The choice of an optimum must adequately describe the system without bias. It is readily apparent that whatever optimum is chosen, it will have a strong effect on the methodology employed. The current most commonly used descriptor is the propulsive efficiency which is defined as the ratio of the power required to the power output of the plant (ref. 5). Efficiencies suffer from differences in definition and thus vary in their relative importance to system optimization. Minimum power required to propel the craft at the desired speeds is sometimes utilized as an optimization objective with the advantage of being readily calculable and understood. A disadvantage is that a gas turbine, which is a commonly used prime mover on account of its low weight to power ratio, operates most efficiently at its maximum power level. Hence, there exists a natural trade-off between the most efficient propulsion and the margin required for growth in the ensuing years of the craft's life. Minimum power calculations are certainly necessary but provide a somewhat questionable optimum. In an attempt to avoid vagaries of definition and usage and

to remove doubts of sufficiency, the goal of optimization or the system "cost" may be defined differently. The "cost" of any system should reflect the disadvantages of that system without weighting one disadvantage over another. Two disadvantages of waterjet propulsion systems mentioned previously are a large system weight, in part due to the entrained water, and a low overall system efficiency. Inefficiencies are, however, necessarily manifested in increased weight, be it added required fuel, another pump stage, or larger ducting. Recall, too, that hydrofoils are weight limited vehicles. A unique number that reflects these realizations is a suitable definition of the weights attributable to the propulsion system (ref. 5). The propulsion system weight shall be defined as the sum of all weights of the structural components, prime movers, fuel, pumps, gearbox, ducting, and entrained water above the mean waterline. If, for a given craft, the displacement is considered constant, then minimization of the propulsion system weight is equivalent to maximizing the craft payload. Thus, a propulsion system shall be defined as optimal if, in addition to fulfilling the propulsion requirements, it adds the minimum weight of any propulsion system to the vehicle.

The generalized waterjet propulsion system for hydrofoils utilized in this study is depicted in Figure 1. It should be noted that this configuration permits

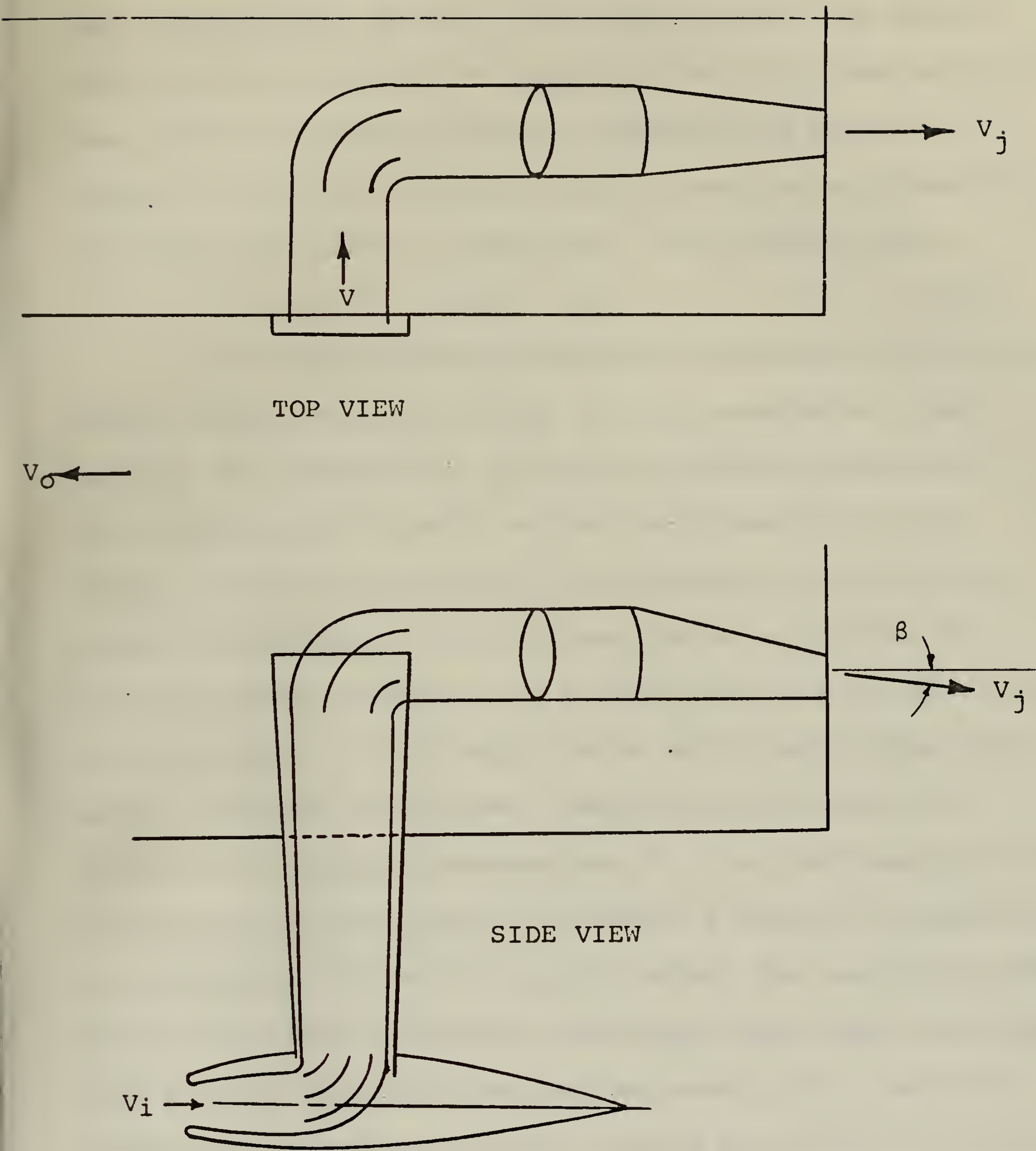

FIGURE 1   GENERAL DUCTING CONFIGURATION

considerable variation by the changing of a few lengths and angles of the ducting. The water enters the nacelle under ram pressure and is ducted up the strut and into the pump where the energy input is converted to kinetic energy in the jet. Thus the thrust reaction is generated, providing the craft's propulsion. In equation form,

$$T = \rho Q (V_j \cos(\beta) - V_o) \tag{1}$$

In any optimization procedure, the formulation of the method requires the knowledge of the parameters to be varied. The number and selection of these parameters contributes significantly to the applicability of the method. The parameters must be necessary and sufficient system descriptors, and it is desirable to utilize the minimum number required. If M operations are performed in the evaluation of one design point and N independent parameters describe the system, then the total number of operations required increases as M^N. The sufficiency of the description of the system is clearly a choice of adequacy. The variables that most strongly affect the resulting system should be chosen as system parameters while other variables that produce only minor variations over a wide range of values on the essential design should be defined, or even somewhat arbitrarily chosen, to suit the needs of the design.

Examination of equation (1) reveals that for a given craft and associated mission, only the flow rate and jet velocity are unknown. The one-dimensional continuity

equation for an incompressible fluid

$$A_1V_1 = A_2V_2 = Q \qquad (2)$$

indicates that choice of jet velocity will determine the jet area. The first non-dimensionalized system parameter, then, shall be V_j/V_o, defined at the cruise point. Knowing the flow rate from the jet, the same reasoning may be applied to the inlet which results in the second system parameter of V_i/V_o, where V_i is defined in the cruise condition at the point of minimum area in the nacelle. The third and last system parameter, for reasons that will be explained in Chapter 3, shall be D_i/D_m, where D_i is the diameter of the inlet at the point of V_i.

Finally, the minimum amount of information needed to specify the craft and its mission must be determined. A typical drag to craft speed curve is shown in Figure 2. The "hump" at the lower speeds represents the take-off point, i.e., when the hull lifts free of the water and the craft is foilborne, and generally occurs at speeds that are approximately 50% of the cruise speed. The sizing of the propulsion system then is dependent on both the cruise and take-off conditions. The minimum information required is the following:

a. Displacement

b. Range

c. Prime mover

d. Craft Speed, at take-off and cruise

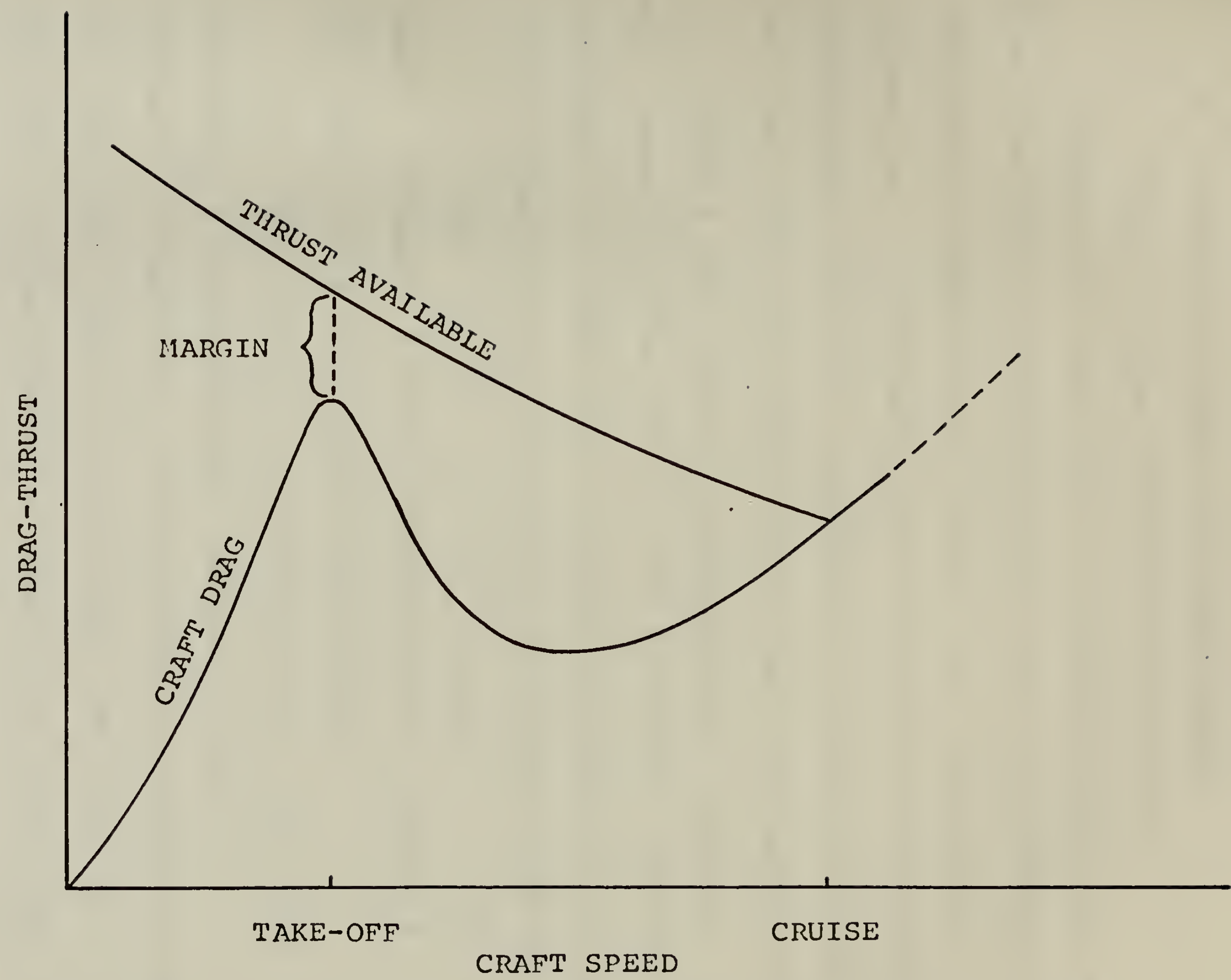

FIGURE 2 TYPICAL HYDROFOIL LIFT TO DRAG VS. SPEED CURVE

e. Craft Drag, at take-off and cruise

f. Depth of submergence of foil

g. Distance of strut from transom

h. Distance of pump exit from transom

i. Height of pump centerline above keel

Although the prime mover is assumed to be a gas turbine, knowledge of the particular type of gas turbine is important in consideration of both fuel and power requirements. It is readily seen that the last four input requirements define the approximate configuration while the first five items describe the craft size and mission.

Knowing the required ingredients and the desired result leaves only the recipe to be set forth. For the traverse of an ideal fluid between two points in a closed conduit, Bernoulli's equation may be applied such that

$$p_1 + \tfrac{1}{2}\rho V_1^2 + \rho g z_1 = p_2 + \tfrac{1}{2}\rho V_2^2 + \rho g z_2 \qquad (3)$$

where 2 indicates a station downstream of station 1. For a real fluid with losses this becomes

$$p_1 + \tfrac{1}{2}\rho V_1^2 + \rho g z_1 = p_2 + \tfrac{1}{2}\rho V_2^2 + \rho g z_2 - \Delta p_{12} \qquad (4)$$

where Δp_{12} = losses between stations 1 and 2.

Although this equation can be applied only along a streamline and hence cannot be used across the pump, it is applicable to the ducting on either side of the pump. The continuity equation provides the information that the ducting velocities are determined by geometric configuration. Starting from a known point, e.g. the water surface,

and following the water through the duct leaves only the losses as unknown. Estimation of the losses may be accomplished based on duct size and shape (ref. 8). This yields the needed information for the pump design.

Following the flow diagram of Figure 3, and recalling the previous discussion, the choice of the system parameters by the technique described in Appendix A determines the inlet and outlet geometry. Knowledge of the jet area determines the flow rates at both cruise and take-off. Water is ingested into the nacelle at velocity V_i. The parameter D_i/D_m sets the amount of diffusion possible prior to entry into the strut elbow. Determination of the nacelle length provides both a drag estimate and the head loss in the nacelle duct as described in Appendix B. The strut elbow will exhibit large losses due to the low aspect ratio (width/depth) of the duct as it conforms to the shape required for the strut and due to the relatively large velocities. The use of guide vanes will minimize the losses by increasing the aspect ratio. Assuming the inlet and outlet areas are the same, the losses in the elbow may be calculated by the method described in Appendix C. The strut diffuser area ratio is set to avoid cavitation in the downstream ducting and to reduce the inflow velocity to the pump. Sizing the internal flow area permits an estimate of the exterior dimensions which are sized up to cavitation limits. For more information,

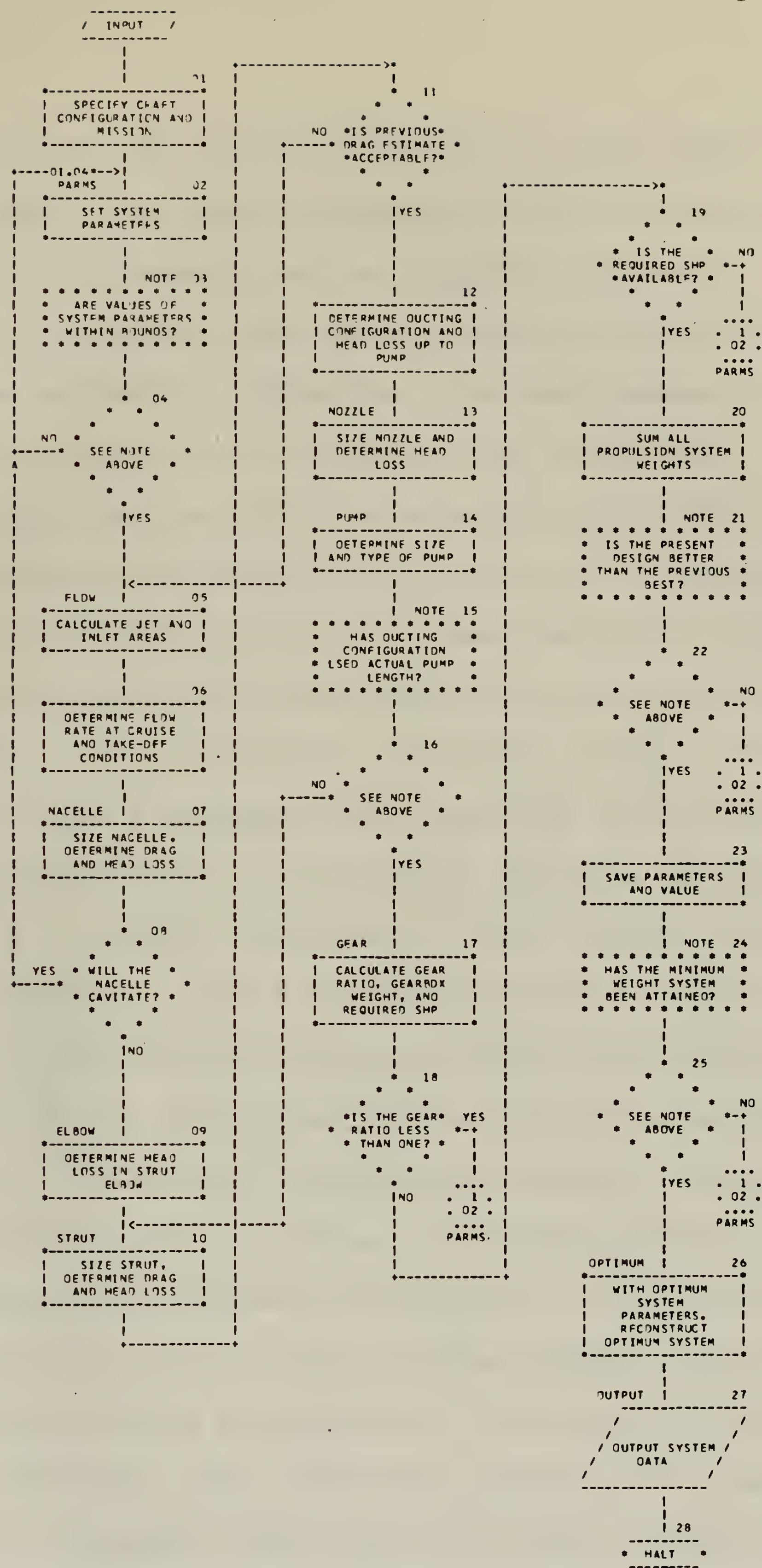

FIGURE 3 DESIGN METHODOLOGY FLOW DIAGRAM

see Appendix D. The drags attributable to the strut and spray are estimated. The newly calculated nacelle, strut, and spray drags are compared to the original estimates. If the deviation is excessive, the drag estimate is revised and the problem restarted. Otherwise, the head losses in the strut due to friction and diffusion are calculated. Entry into the hull from the strut is made via a 90° elbow for which the losses are calculated as before. It should be noted that this elbow will have a more favorable aspect ratio as a result of the strut shape and will require fewer guide vanes. Coupled with the decreased velocity, the losses will show a decrease from those due to the strut elbow. Determination of the ducting required, as described in Appendix E, permits estimation of the ducting losses therein. Summation of all the losses prior to the pump and knowledge of the inflow velocity provide the cavitation information in the form of net positive suction head (NPSH) to the pump. Adding the nozzle losses permits calculation of the pump head required. The method for determining the nozzle losses may be found in Appendix G. This is sufficient to determine the size and type of pump needed, the details of which may be found in Appendix F. The specifications of the prime mover are then utilized to specify the gearbox parameters of gearbox ratio and power which in turn indicates the SFC required in the cruise condition. Since the

amount of fuel required for the endurance specified is calculable, the entire propulsion system is fully defined in dimensions, configuration, weights, and particular components. Summing all the component weights yields the desired system weight. This concludes the evaluation of a propulsion system weight for the chosen system parameters. The optimization routine utilizes the weight information, selects a new set of system parameter values and the cycle begins anew. Ultimately, the minimum weight system is located and the process completer.

CHAPTER 3 - DISCUSSION OF RESULTS

A sample output is depicted in Figure 6. The first page is predominantly a repetition of the input data and is printed out upon call to the program. The second and third pages are the resulting optimized system data that is printed for each configuration of pumps and gas turbines considered. Hence the designer can see at a glance the pertinent information required for a preliminary design as well as compare the alternative configurations that might be feasible and competitive designs.

There are a number of features within the results that are not immediately obvious. First and foremost is the problem of results exceeding a system limitation. For example, having required cruise shaft horsepower exceeding the maximum normal horsepower of the engine. Within the program during the optimization, such designs are, of course, rejected. For the print out, it was considered that knowledge of the resulting "optimum" was desirable, however erroneous it may be. One of the forcing influences on this decision was the variability of the total drag estimation and thus the flow rate. If the optimum system resulted in a value that was at a boundary, a slight change in, say, flow rate might cause the value to exceed the boondary and hence result in a rejected design. In other words the optimum system is not identically reproducible. The significance of this fact will be amplified in the

conclusions section. This lack of reproducibility results primarily from the iterations for drag estimation. Each new estimation is compared to the previous estimation and accepted if within 5% of the former value. Otherwise the flow rate is adjusted for the new drag and the nacelle and strut are redesigned. In the case of the 400 ton craft used, 5% of the total drag is on the order of 4000 pounds force in the cruise condition. Thus, starting from the same system parameter values but with different initial drag estimates may result in a total drag differing by 5% in the output with corresponding differences in the system.

Secondly, the resulting design is obviously constrained by the ducting configuration used. Hence direct comparison with existing craft is not valid until the configuration is modified to conform to that of the craft.

At the inception of this project, it was believed that the duct area ratio of the strut was a system parameter to be varied independently. Clearly a lower bound on this parameter is that amount of diffusion required to avoid cavitation in the hull ducting. It was felt, however, that the pump, gear and fuel weight calculations might reflect a lower overall weight if the pump inflow rate was reduced. The results did not justify this assumption. The system unerringly chose the strut with the minimum required diffusion, which meant minimum weight. The principal reason for this result is that the pump design is in terms

of total head. Hence the pump effectively never "sees" the amount of static head presented to it. The pump is affected only by the differences in ducting losses which are reflected in both the NPSH and pump head. Thus the net effect is of secondary importance and is not significant enough to change the area ratio of the strut. For this reason the area ratio of the strut ducting was rejected as a system parameter and is presently determined as required by cavitation limitations or pump inlet area.

The initial nacelle design method chose the largest inlet to maximum diameter ratio permissible by exterior cavitation. This ratio was tempered by the amount of diffusion required to avoid cavitation in the strut elbow. Assuming the same inlet velocity ratio, would more diffusion than the minimum required permit an overall lesser weight system? In other words, does the optimum system require the optimum nacelle or might an off design nacelle be used resulting in a lesser weight system? The use of the nacelle diameter ratio, DIDM, as a system parameter provides the opportunity to investigate this question. The current results are somewhat inconclusive due to the influence of other factors. Tentatively, it is suggested that for some designs, the use of DIDM as a system parameter is justified and results in a better system design. It is recommended that investigation of this question be pursued for determination of what constitutes the basis of nacelle

design in regards to system performance.

Perhaps the most significant conclusion is that the choice of engine is extremely important in the resulting optimum system. The first reason for this is that the gas turbine is presently available only at discrete power levels. Since fuel weight is large relative to the other system weights, the operation of a gas turbine at a point significantly off its design point will result in a large increase in fuel weight and thus system weight. The net effect is that, given the opportunity to avoid the penalty in fuel weight, the system tends towards the maximum SHP permitted by the engine, and will drive the jet velocity ratio as high as possible to achieve this SHP. This also results in a low flow rate, low drag and low propulsive coefficient. If the engine is slightly large for the craft, then the results will show a high jet velocity ratio, SHP per engine at the maximum permissible level, which may be limited by take-off <u>or</u> cruise SHP, and a low propulsive coefficient. If the engine is so large that there is no power limitation, the jet velocity ratio will be very high and the SHP per engine relatively low resulting in a very low propulsive coefficient due to large total SHP and a high system weight. The effect of an engine that is barely adequate is a lowered jet velocity ratio in an effort to reduce the SHP requirements. The trade-off here is the large flow rate required to compensate for the low jet

velocity ratio and the large drag that results from attempting to accomodate the flow rate in the nacelle and strut. Thus SHP is being forced up and the system may never achieve an acceptable horsepower level.

This power level sensitivity is so strong that it is abundantly clear that hydrofoils should be designed around a particular gas turbine. Choice of a desired displacement and the use of an adequate prime mover may result in a poor design and inefficient use of the gas turbine. Choice of the gas turbine and permitting the displacement to be chosen at the point of best engine operation will result in a more efficient and more effective design. Thus it is recommended that another version of this program be created that chooses the best displacement given the engine. It is also suggested that perhaps the concept of hydrofoil craft design be revised to accomodate the fact that the engine choice determines the best design. Figure 7 shows the minimum weight ratio for one LM2500 and one pump with a lift to drag ratio of 11.3. The results show the optimum weight ratios with and without fuel do not coincide. The propulsive coefficient is drawn to show the trade-off between maximizing SHP and maximizing the propulsive coefficient.

The choice of an engine also affects the reproducibility of the optimum system design. If the engine is smaller than desirable, VJVO is driven as high as the SHP permits.

When the optimum system parameters have been found and the optimum system is to be regenerated, the design process is reinstituted. During this final design, iterations in craft drag are again required to determine the final flow rate and size of the system. Thus the net result may be a system slightly different from the one originally found with least weight. And in the case of a system already on a boundary, the resulting system may exceed the limits placed on the optimization process. It is to be expected that the deviation will be small but nonetheless present. The results in such a case should be interpreted as optimal at the boundary and not an unsatisfactory design. If the deviation is significant and the other system values reflect it, the interpretation should be that the system was unable to be optimized within the limits. The most common example of this occurs when the cruise or take-off SHP of the engine is insufficient to meet the craft requirements.

The effect of range on the system design is shown in Figure 4. The LM 2500 is a power limited engine for the four hundred ton craft at forty-two knots. The FT4C-2, however, is so large that maximum power is never attained in this craft. The effect of lower SFC and operation at maximum power favors the LM 2500 at the longer ranges. As it should be, the weight ratio without fuel is essentially constant for both engines, although the weight ratio for the

LM 2500 is higher, presumably on account of the power limitation. Similarly, the jet velocity ratio remains constant as does the flow rate, but the inlet velocity ratio tends to increase with increasing range. The nacelle diameter ratio, on the other hand, shows no consistent pattern. The effect of variation of displacement by 10% is shown in Figure 5 for the FT4C-2 for one and two pumps.

The results show a surprising sensitivity to the starting values of the system parameters. When arbitrarily deviated by twenty per cent from the present values, the results were unpredictable. The current values, however, have shown good stability with test craft ranging from fifty to seven hundred fifty tons and from forty to fifty knots. The reason for this apparent instability is unknown. The step sizes appear to be acceptable at any size above a threshold value. Some conditions will not permit location of the optimum if the step size is too small. The current step sizes, although generally too large, have performed well for the test craft above. The probable rationale is that the large step size permits a search over a wider, more extreme range of system values, but in the event that the step is too large, the step size will rapidly be reduced to an acceptable level.

The lack of experimental data and analytical techniques has been noted in several areas. The nacelle design is a case in point. Although nacelles have been studied exten-

sively by the aeronautics industry, the application of nacelles to a water environment has been neglected and consequently, design considerations have not been defined. The design of cascaded corners has somewhat more experimental data for loss estimation, but the scatter of the data and the lack of definitive design information render elbow design a vague approximation at best. Three dimensional diffusers are likewise an unexplored domain. The effect of changes of ducting shape on losses is not treated in the literature for straight pipe. Loss estimation for changing shape in elbows is treated, but only for rectangular forms. It is apparent that the program results contain a great deal of information, but it is also evident that the interpretation of the results can be improved by a more thorough study of runs for different craft, configurations, and missions. A study of the effects and interactions of such changes will provide a finer understanding of the import of the results.

CHAPTER 4 - CONCLUSIONS AND RECOMMENDATIONS

A method of optimizing a waterjet propulsion system for hydrofoils has been developed and tested with a four hundred ton hydrofoil at a cruise speed of forty two knots. Other craft have verified the importance of the selection of the gas turbine for a particular craft. It is recommended that a version of this program be adapted to determine the optimum displacement for a given engine.

Although originally considered important, the amount of diffusion in the strut should be the minimum required to avoid cavitation in the ducting or the minimum required by the pump, whichever is greater. The design of the nacelle need not be at the limits of cavitation, but should be integrated into the total system design to provide a lesser weight propulsion system. It is recommended that a study of nacelle design be initiated to determine the interaction of the nacelle and the propulsion system.

The initial values of the system parameters may affect the operation of the optimization procedure. A determination of the cause of this lack of stability should be made. The magnitude of the step sizes of the parameters has little effect on the program provided they are sufficiently large.

A general lack of data and design information is prevalent for fluid flow in closed conduits. This is especially noted for ram inlet design, cascaded corners, three dimensional diffusers, and changes of pipe shape.

The program provides a unique facility for the preliminary designer to rapidly ascertain the optimum waterjet propulsion system design and performance. Many results should be studied to deduce the complete real world interpretation of a computer generated design.

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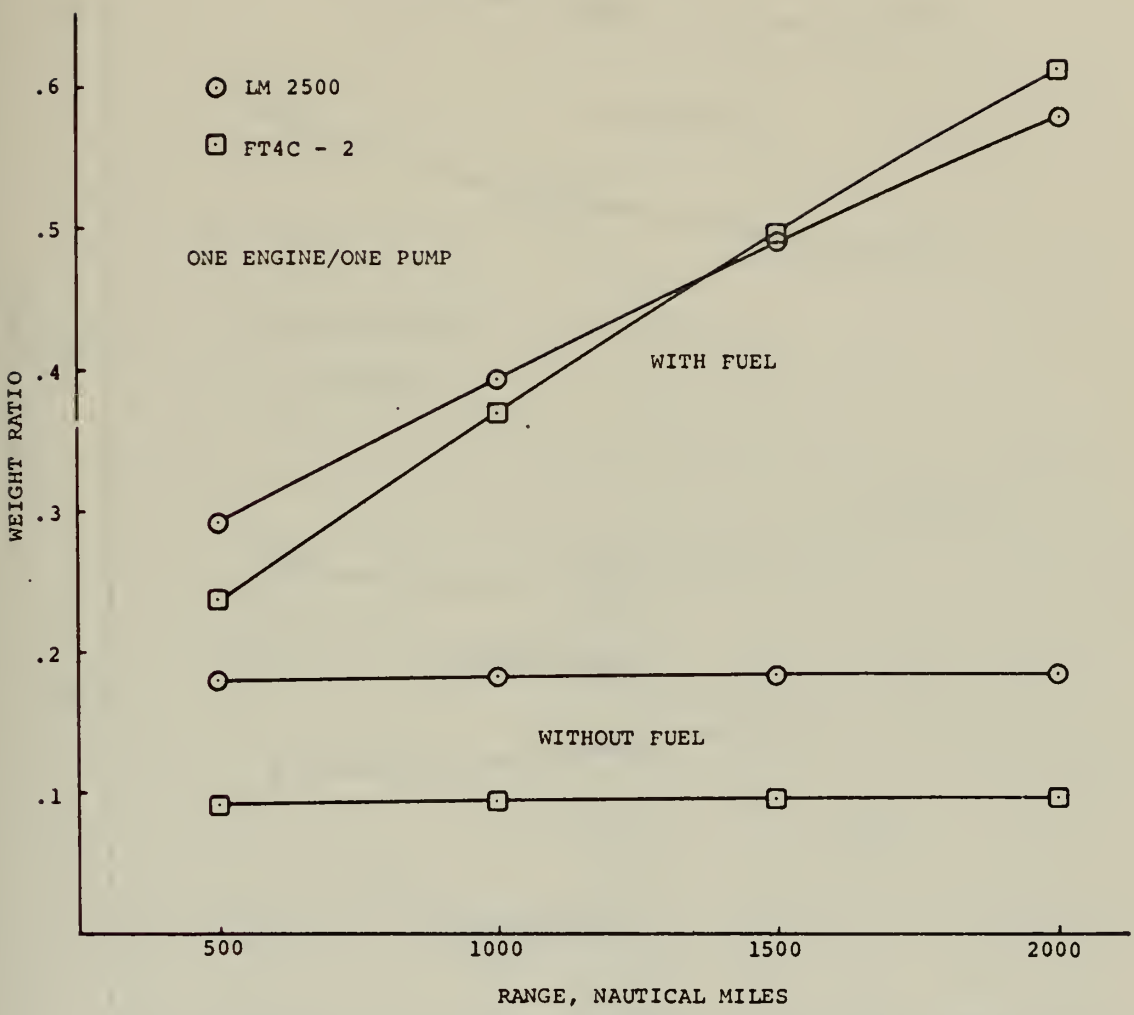

FIGURE 4

WEIGHT RATIO VS RANGE

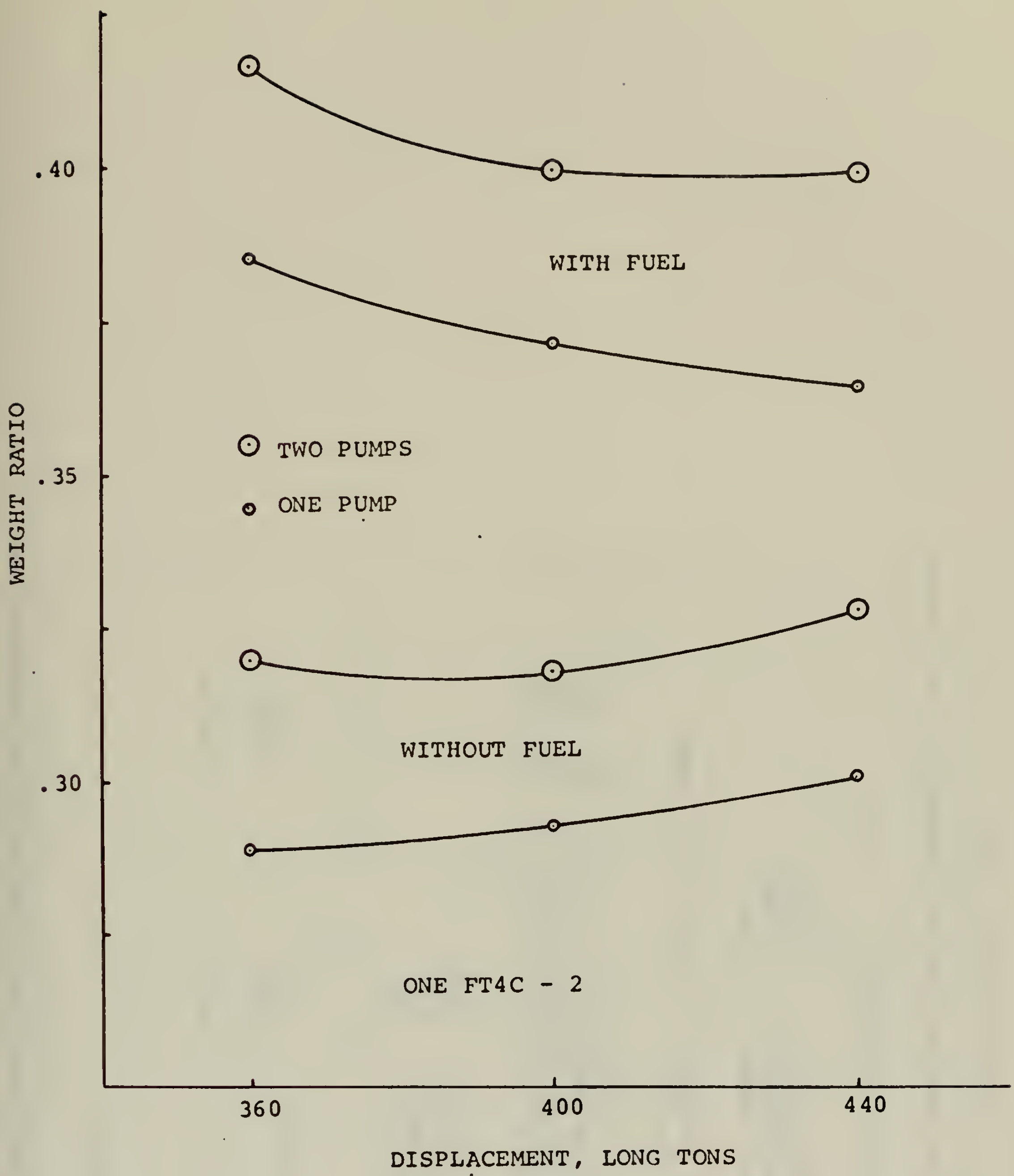

FIGURE 5

WEIGHT RATIO VS DISPLACEMENT

```
*** WATERJET PROPULSION SYSTEM DESIGN AND PERFORMANCE ***


CRAFT CHARACTERISTICS


OPERATIONAL

                              CRUISE              TAKE-OFF

VELOCITY, KNOTS                42.0                 21.0
TOTAL DRAG, LBS               79250.              101204.
ANGLE OF ATTACK, DEGREES        0.0                  2.C


CONFIGURATION

AVERAGE BEAM, FEET.........   42.0
DISPLACEMENT, LONG TONS....   400.
ENDURANCE, NM..............  1000.
GAS TURBINE PLANT..........   FT4C-2


DEPTH OF SUBMERGENCE OF NACELLE................  5.0  FEET
HEIGHT OF PUMP CENTERLINE ABOVE MEAN WATER..... 10.0  FEET
HEIGHT OF PUMP CENTERLINE ABOVE KEEL...........  2.0  FEET
DISTANCE OF STRUT FROM TRANSOM................. 20.0  FEET
DISTANCE OF PUMP EXIT FROM TRANSOM.............  2.0  FEET


          WATER PROPERTIES
          (ASSUMES STANDARD(3.5% SALINITY) SALT WATER)


TEMPERATURE, DEGREES FAHRENHEIT      59.
DENSITY, LBF-SEC**2/FEET**4          1.989
VISCOSITY, *10**5, FEET**2/SEC       1.279
VAPOR PRESSURE, FEET                 0.545


ACCELERATION OF GRAVITY, FT/SECS**2       32.174


NO EQUIPMENTS OR CONFIGURATIONS SPECIFIED. GENERATED AS PER PROGRAM
```

FIGURE 6 SAMPLE OUTPUT DATA

*** SYSTEM WEIGHT IS 148.20 TONS ***

NUMBER OF GAS TURBINES IS 1
NUMBER OF PUMPS IS 1

**** WATERJET PROPULSION SYSTEM OUTPUT DATA ****

INLET AREA, TOTAL, FEET**2	7.90
STRUT DIFFUSER AREA RATIO	1.71
JET AREA, TOTAL, FEET**2	1.64

FLOW RATE CFS	JET VELOCITY	JET VELOCITY RATIO	INLET VELOCITY	INLET VELOCITY RATIO	SHP PER TURBINE	PROPULSIVE COEFFICIENT	
321.57	196.27	2.77	40.76	0.57	23472.	0.4379	CRUISE
354.45	216.07	6.10	42.56	1.20	34549.	0.1891	T/O

RADIUS RATIO	DUCT RADIUS	ANGLE DEGREES	LOCATION	SHAPE
1.50	1.76	90.00	STRUT	RECTANGLE
1.50	1.15	90.00	HULL	RECTANGLE
1.50	1.83	90.00	PUMP	CIRCLE

	STRUCTURE WEIGHTS (POUNDS)	WATER WEIGHTS (POUNDS)	CRUISE DUCT LOSSES (FEET)	T/O DUCT LOSSES (FEET)	EVALUATION DUCT LOSSES (FEET)
NACELLE	1068.2	0.0	2.26	2.30	
STRUT ELBOW	816.0	0.0	2.09	2.47	
STRUT DIFFUSER	5603.8	14956.8	0.33	0.39	
HULL ELBOW	1048.1	3658.9	0.82	0.97	
ATHWARTSHIPS LENGTH	4593.8	21413.7	0.14	0.17	
PUMP ELBOW	1787.7	5837.8	0.31	0.37	
FORE AND AFT LENGTH	0.0	0.0	0.00	0.00	
PUMP	10310.4	5670.7			
NOZZLE	360.4	1222.2	1.08	1.33	
REDUCTION GEAR	1487.5	0.0			
FUEL	0.0	249093.4			
FT4C-2	14200.0	0.0			
JET LIFT	0.0	-11152.7			
TOTALS	41265.8	290700.6	7.03	8.00	

FIGURE 6 SAMPLE OUTPUT DATA (CONT.)

PUMP DATA

CENTRIFUGAL PUMP WITH 10 DOUBLE SUCTION IMPELLERS PER PUMP

HEAD	NPSH	THOMA	RPM	EFFICIENCY	
537.6	94.7	0.176	1275.3	0.876	CRUISE
724.0	35.4	0.049	1462.8	0.882	T/O

```
SPECIFIC SPEED,CFS................   44.1
SUCTION SPECIFIC SPEED,CFS........  424.5
FLOW COEFFICIENT..................  0.140
HEAD COEFFICIENT..................  0.596
INLET TIP DIAMETER,FEET...........   1.18
EXIT TIP DIAMETER,FEET............   2.58
PUMP LENGTH,FEET..................  18.67
GEAR RATIO........................   2.46
```

NACELLE DATA

```
DIAMETER RATIO,DI/DM..................... 0.719
MAXIMUM DIAMETER,DM,FEET................  3.12
INLET AREA PER NACELLE,FT**2............  3.95
AUXILIARY INLET AREA PER NACELLE,FT**2    0.22
FOREBODY LENGTH,FEET....................  1.34
LIP LENGTH,FEET.........................  0.15
DIFFUSER LENGTH,FEET....................  3.87
NACELLE LENGTH,FEET..................... 17.16
```

STRUT CONFIGURATION

T/C	THICKNESS	CHORD	
0.130	1.7	12.7	ROOT
	1.3	9.7	TIP
	1.4	10.9	WATERLINE

DRAG ESTIMATES

TOTAL	NACELLE	STRUT	SPRAY	
79755.3	4092.3	2648.4	2014.7	CRUISE
101389.3	1143.1	742.6	503.7	T/O

TOTAL SYSTEM WEIGHT RATIO IS 0.3705

SYSTEM WEIGHT RATIO WITHOUT FUEL IS 0.0925

FIGURE 6 SAMPLE OUTPUT DATA (CONT.)

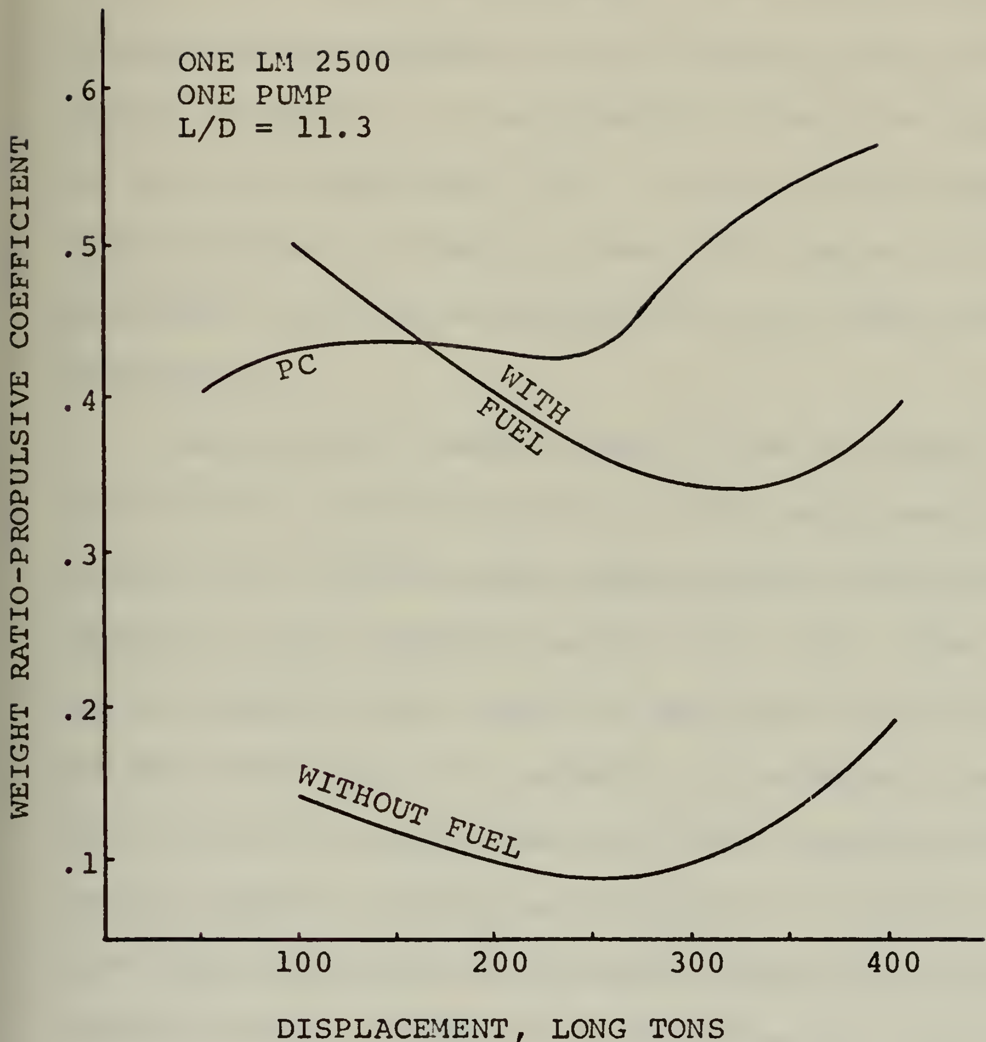

FIGURE 7 WEIGHT RATIO/PROPULSIVE COEFFICIENT VS DISPLACEMENT

APPENDIX A - OPTIMIZATION

The selection of an optimization procedure represents a key consideration in the overall design method. For one thing it may require computations to be made solely for its usage, as in gradient methods. Then, too, it may require a supervisory program to tell it what to do, as in random search techniques, or an adaptive direction capability may be self-contained (ref. 18). It is not the intent of this investigation to find or invent the "optimum" optimization procedure, but the significance of its usage should not be minimized.

The general consideration of how to optimize has a wide variety of tools to aid in the achievement of the answer. One of the more common methods utilized is some variant of the gradient search (ref. 19). The rationale is an intuitive one, based on the notion that if the goal is the attainment of a maximum, for example, the quickest way to go is in the direction of the steepest slope. This is not unlike a blind man's method of climbing a mountain. Like the blind man, the gradient search can encounter difficulties by following this philosophy. The assumption of a finite slope in the area of interest not only requires the absence of steps on the hypersurface, but imposes the more stringent limitation that the slope be calculable and containable within the computer. This somewhat limits the types of systems that can be optimized by this technique and

and exacts a stiff penalty for some numerical inaccuracies. Further, assuming that the system to be optimized permits slope calculations, it is not known a priori that such calculations provide sufficient information to compensate for the time spent in making them. In the present system design, discrete steps are virtually guaranteed due to the different pumps and gearboxes used. Since computation of the propulsion system weight is not done by means of an analytic function, slope calculations become as lengthy as the weight calculations themselves. For these reasons, gradient search techniques are rejected as a possible optimization tool for this design problem (ref. 20).

On the opposite end of the optimization spectrum lies the random search. The principal advantages of a random search are the ease with which it may be understood, hence used and programmed, and the simplicity of its computation. No slopes or step sizes need to be calculated or estimated, merely the values of the function at the points of interest. This is also its major disadvantage.

The random search also has no greater likelihood of finding a local optimum than it does of finding the global, and, hence desired optimum. Once the capability of "directionability is gained, local optima are just as likely to be found as the global optimum as is the actual optimum. This is true of all directed searches. The only way to avoid this unpleasant result is to use random starting points

[illegible]

or to use a systematic search over the entire hypersurface. A unimodal surface, of course, does not present this problem.

Since the random search utilizes no other additional information than the function value, it is highly inefficient with the result of greater time spent in the search. All optimization is done in comparison to the previous best. Thus the simplicity of its procedure is gained only at the sacrifice of the large number of evaluations that must be made to assure a reasonably high certitude of attaining the optimum. This becomes especially significant when the time of calculation of a single function value is lengthy. In the design and performance estimation of a propulsion system, a lengthy calculation is likely to be the case, in part due to the iterative loops required (refs. 21, 22).

The solution is clearly somewhere in the middle of these two approaches, utlizing the best features of each and minimizing their disadvantages. It should have the ability to discern direction without the requirement of additional calculations. One such method is the pattern search utilized in this design (ref. 23). The basis of this method is akin to that of the gradient search but is modified in its approach. Again based on intuition, the pattern search depends on the supposition that the search effort should be expended in the direction of improvement. Note that this is a

[illegible]

[illegible]

[illegible]

qualitative judgment rather than a quantitative one, as with gradient methods. The criterion for a sense of direction lies in the success of an evaluation, not in its measure of success, which in itself would be somewhat arbitrary. Thus, while gaining adaptive information about the location of an optimum, the disadvantages of the gradient search are neatly bypassed and the random search is effectively utilized in a more efficient manner.

Following the flow diagram of Figure 8, the pattern search uses the starting point as the initial basepoint. From the basepoint exploratory moves are made. That is, each coordinate is varied from the basepoint position the amount of the step size and the function evaluated at that point. Each exploratory move is examined for possible improvement in the function value. If improvement cannot be made in any direction, the step size is decremented and the exploratory moves resumed from the basepoint. If a position is located with a better function value than the value at the basepoint, the second type of move, a pattern move, is made. A pattern move is a simultaneous change in all dimensions of length equal to the distance from the current basepoint to the present position. If improvement is made in either the pattern move or the sequential exploratory moves, another pattern move is made. Lack of improvement resets the basepoint at the position of the best function value and enters the cycle again with exploratory

moves from the current basepoint.

This ability to seek, find, and establish a pattern gives this search an ability to move rapidly in the best direction. It also has the capability of shifting direction or modifying the pattern when required. Step changes in the hypersurface present little problem since slopes are not utilized. With these features the pattern search can move quite readily along steep ridges or narrow valleys which are common "Waterloos" of other search methods, especially gradient methods.

Perhaps it should be mentioned here that the intent is not to totally degrade the gradient search which has its own attributes and an important usefulness in its own right. It is not without shortcomings, however, that might present a serious detriment to the user who is looking for a generalized search method.

The original form of the pattern search as proposed in reference 23 has been modified to conform to the needs of this design problem. An additional modification has been made that is considered an improvement on the initial scheme. During the exploratory move phase of the search, each dimension was initially incremented by a step size and the function evaluated. If the move was a success, the point and its associated value were saved and the next dimension explored. Lack of success meant decrementing the position by a step size and evaluating the function. Again a success-

ful move was followed by retaining the position and value and exploring the next dimension. An unsuccessful move was ignored and the next dimension incremented. The modification implemented is to vary the dimension first in the direction of the last improvement rather than simply incrementing it. Thus anticipating success, time would be saved by not checking a poor direction. The resulting advantage of this modification is, of course, very dependent on the function being evaluated, but is in keeping with the philosophy of the search and is accomplished at a very small cost of time.

APPENDIX B - NACELLE

The details of this section may be found in reference 9, from which the following comments are drawn.

The selection of the system parameter values sets the ratio of the inlet diameter to the maximum external diameter, DIDM. This effectively limits that maximum amount of diffusion that may be carried out in the nacelle. The present design assumes that the maximum amount of diffusion allowed in the nacelle duct is utilized. The nacelle is first checked to ensure that it does not cavitate externally. Prediction of external cavitation rejects that selection of system parameter values. If cavitation is not predicted, the inlet is checked for cavitation at the point of maximum flow, which generally occurs in the take-off condition. If cavitation was predicted internally, auxiliary inlets are sized to reduce the inflow rate to just below the point of cavitation. The length of the nacelle is then suboptimized to be the length at which the total power loss due to drag and diffusion in the duct is minimized. The total head loss, made up of the lip loss and the diffuser losses may then be calculated. Likewise, the drag coefficient may be calculated from Hoerner's approximation for stramlined bodies (ref. 10), based on wetted surface,

$$C_d = C_{f_s}\left(1+1.5\left(\frac{D_m}{L_n}\right)^{\frac{3}{2}}+7\left(\frac{D_m}{L_n}\right)^{3}\right)$$

APPENDIX C - ELBOWS

All elbows in the ducting are treated in identical fashion, although individually each elbow may be very different. The inlet and outlet areas for any bend are assumed to be the same. An elbow is considered fully defined by the knowledge of four quantities: width, depth, cross-sectional area, and radius ratio. The radius ratio, $\frac{R}{RO}$, is the ratio of the radius of the centerline of the bend to the duct radius, as depicted in Figure 9. Since the flow rate, Q, has been previously determined, the first three items are sufficient to calculate the aspect ratio, shape, and the mean velocity of the fluid in the elbow.

For $Re(\frac{RO}{R})^2 > 91$, Ito's expression for the head loss coefficient in a circular bend is (ref. 11):

$$K_t = .00241\alpha\theta Re^{-0.17}(\frac{R}{RO})^{0.84} \qquad (C.1)$$

α is a numerical factor dependent on θ and $\frac{R}{RO}$. For the case of $\theta = 90°$ and $\frac{R}{RO} < 19.7$

$$\alpha = 0.95 + 17.2(\frac{R}{RO})^{-1.96} \qquad (C.2)$$

The loss coefficient then is

$$K_t = 0.00241\theta[0.95 + 17.2(\frac{R}{RO})^{-1.96}]Re^{-0.17}(\frac{R}{RO})^{0.84}$$

For a given duct and considering θ, V, and R constant, partial differentiation of K_t with respect to RO leads to

$$\frac{\partial K_t}{\partial RO} = 0 \implies \left(\frac{R}{RO}\right)_{opt} \approx 4.3$$

Since $K_t \approx \frac{C_1}{RO} + C_2 RO$ for these conditions, this result verifies the intuitive feeling that a minimum exists due to a trade-off between friction and bend losses as the number of guide vanes in the elbow varies, as depicted in Figure 10.

If the given radius ratio is greater than one, the losses in the elbow may be reduced by the use of splitters which aid in the prevention of separation. In this context, splitters are defined as guide vanes of unequal length, unequal spacing and possibly unequal curvature (ref. 12). Turning vanes, on the other hand, are always equal in length and curvature, although the spacing between vanes is not necessarily equal. If the splitters are considered in order to subdivide the elbow into smaller elbows, the minimum loss will occur when the ratio of the inside radius to the outside radius of any of the subdivided elbows is constant. Referring to Figure 6, this may be written as

$$\left(\frac{r_i}{r_o}\right)_A = \left(\frac{r_i}{r_o}\right)^{1/n}$$

where n is the number of subdivided elbows, i.e. the number of splitters + 1. Figure 11 depicts a duct with one splitter. Clearly,

$$r_i = R - RO$$

$$r_o = R + RO$$

Hence, the desired radius ratio, 4.3, may be substituted for $\frac{(ro_a+ri_a)}{(ro_a-ri_a)}$ and the resulting equation solved for n, or,

$$n= \frac{Ln\left[\frac{\frac{R}{RO}-1}{\frac{R}{RO}+1}\right]}{Ln\left[\frac{4.3-1}{4.3+1}\right]} = 2.12\ Ln\left[\frac{\frac{R}{RO}+1}{\frac{R}{RO}-1}\right] \qquad (C.4)$$

The number of splitters determines the spacing. The head loss coefficient may be calculated for each subdivided elbow and the results averaged over the area which will yield the average head loss coefficient for the elbow.

For $\frac{R}{RO} < 1$, equation C.4 has no meaning. For this case the total head loss coefficient was computed as the sum of the friction loss coefficient and the loss coefficient from Figure 12 which is an empirical graph for thin, circular arc turning vanes from reference 12.

In either case the results are valid up to a Reynolds number below that expected in this design. The head loss coefficient including friction is then corrected for the higher Reynolds number by (ref. 13)

$$K_2 = \frac{X_2}{X_1} K_1$$

[illegible]

$$[illegible]$$

[illegible]

[illegible]

[illegible]

where by curve fit,

$$\chi = 1.0057 - 0.16892 \mathrm{Ln}(Re \times 10^{-5}) + 0.0145885[\mathrm{Ln}(Re \times 10^{-5})]^2 - 0.0016948[\mathrm{Ln}(Re \times 10^{-5})]^3 \tag{C.5}$$

APPENDIX D - STRUT

The head losses in the strut diffuser are caused by friction and the area expansion which thickens the boundary layer. The friction coefficient is computed in the same manner as for straight pipe. The expansion loss coefficient is

$$K_e = C(1- \frac{A_i}{A_o})^2 \tag{D.1}$$

C is dependent on the diffuser equivalent angle, 2θ, and is interpolated from the graph in Figure 13, which is for a two-dimensional, straight-walled diffuser. For the flow area, the thickness to chord ratio of the strut is held constant while the area is increased. Hence the assumption of two dimensional diffusion is not strictly valid but is considered a conservative estimate.

The strut dissipates energy externally by a drag term attributable to the body and a term resulting from the spray. The drag coefficient from Hoerner (ref. 10) is based on the planform area and is approximated by

$$C_{d_s} = 2C_{f_s}[1+2(t/c)+60(t/c)^4] \tag{D.2}$$

The spray drag coefficient, likewise based on planform area is

$$C_{d_{sp}} = .03(t/c) \tag{D.3}$$

This approximation is valid for Froude number, based on the chord length, greater than three (ref. 14).

[illegible]

APPENDIX E

Pump Inlet Piping

The ducting from the hull elbow to the pump inlet is a straight pipe, a 90° elbow and a transition piece. The length of the straight pipe depends on the number of prime movers. In equation form,

$$\text{Length} = \frac{\text{Beam}}{\text{Number of prime movers} + 1}$$

The transition piece is shaped according to the number of pumps under consideration. Since there are two struts ducting water into the hull, assuming a canard foil arrangement, and only one, two, or four pumps are considered, the transition piece will be a junction, straight pipe, or diverging branch.

All straight pipe loss calculations are made using the standard Darcy-Weisbach equation

$$h = \frac{fL}{D_e}\frac{V^2}{2g} \qquad \text{(E.1)}$$

The Moody friction factor, f, is computed using the closed form approximation of Techo et al (ref. 15),

$$f = [.86859\ \mathrm{Ln}(Re/1.964\mathrm{Ln}(Re) - 3.8215))]^{-2} \qquad \text{(E.2)}$$

R_e is based on the mean hydraulic diameter which is defined as

$$D_e = \frac{4A}{P} \qquad \text{(E.3)}$$

This approximation for the friction factor is accurate to within .1% over the range of Reynolds number from 10^4 to

2.5×10^8.

For both the junction and divergence, the average velocity is assumed to be the same before and after the transition piece and the piping is symmetrical about the single pipe as shown in Figure 14. This requires that the smaller piping cross-sectional area is 1/2 that of the larger piping.

The mixing loss coefficient in the junction, without friction loss, is computed from

$$K_j = 1 + \lambda - 2\cos(f(\phi)) \qquad \text{(E.4)}$$

where $f(\phi) = 1.4\phi - .00583\phi^2$

and ϕ is the angle the small branch makes with the larger duct (ref. 16). In the cases examined for this design, ϕ was set to zero resulting in only friction losses in the junction.

The divergence loss factor λ was computed from Figure 15 which is adapted from reference 16. The angle of the divergence, of course, depends on the pump length. It should be noted that the divergence configuration requires another elbow, equal in angle to that of the divergence, to enter the pump.

In all three transition pieces the size was set as required, depending on the pump length. If the pump's length requires a zero or negative transition piece length, the transition piece is neglected and the losses computed only for the athwartships length and the pump elbow

which turns the ducting aft.

APPENDIX F

Pump

The details of this appendix may be found in reference 17, from which the following comments are drawn.

There are two basic types of pumps considered in this design: a multistage, double impeller centrifugal design and an axial pump with an inducer impeller. The variations occur in the number of stages used. The pump design utilizes the flow rate and Thoma's criterion is defined as

$$\sigma = \frac{\text{NPSH}}{\text{Pump Head}} \qquad \text{(F.1)}$$

where the net positive suction head,

$$\text{NPSH} = \frac{V_o^2}{2g} + h_a - h_v - h_{elev} - \Delta h_i \qquad \text{(F.2)}$$

and

$$\text{Pump Head} = \frac{V_j^2 - V_o^2}{2g} + h_{elev} + \Delta h_t \qquad \text{(F.3)}$$

The axial pump's first stage is an inducer impeller with up to two additional stages available if the amount of head is sufficiently high. Assumption of a specific speed yields the design pump speed and approximation to the off-design pump speed, which in this case is the cruise condition since the pump is basically designed for take-off conditions. The RPM of the prime mover determines the gear ratio and calculation of the shaft horsepower permits an estimation of the gear weight. Finally, a fuel weight may be calculated for the range specified in

the cruise condition.

The centrifugal pump is designed in the same way except that the number of double suction impellers is increased, thus increasing the RPM, until the combined weights of the pump, dry and wet, gearbox and fuel are at a minimum.

The two resulting pump designs are then compared on the total pump, fuel, and gearbox weights and the least weight system is selected for the propulsion plant.

APPENDIX G

Nozzle

For the purpose of calculation the nozzle was considered a straight-walled nozzle. Assuming the losses are of the form

$$h_n = f \frac{L}{D} \frac{V^2}{2g} \tag{G.1}$$

and noting the friction factor is approximately constant and the velocity essentially uniform, this may be written

$$\Delta h_n = f \frac{\Delta L}{D} \frac{V^2}{2g}$$

or

$$h_n = f \int_0^{L_j} \frac{1}{D} \frac{V^2}{2g} dL$$

Substituting

$$D = D_j + L\tan(\psi)$$

$$V = \frac{4Q}{\pi D^2}$$

results in

$$h_n = f \frac{L_j/2}{D_t - D_j} \left[1 - \left(\frac{16}{\frac{1+D_t}{D_j}}\right)^4\right] \frac{V_j^2}{2g} \tag{G.2}$$

which is used for the head loss estimation in the nozzle when $D_t > D_j > 1$, (ref. 2). When $D_j < 1$, the head loss is assumed to be 1.5% of the dynamic head.

In the event that the distance of the pump exit from the transom is greater than 2 times the height of the pump centerline above the keel, the nozzle is assumed to exit through the underside of the craft. The latter distance

is that if the nozzle were directed along an axis at 45° from the vertical.

In every instance, however, the nozzle is assumed to be depressed at the optimum angle to reduce the lift required which would allow the use of smaller foils and hence reduce drag. As before,

$$T = \rho Q(V_j \cos(\beta) - V_o) \tag{1}$$

Rewritten this is also

$$T = (W - T_v)\frac{D}{L} \tag{G.3}$$

where

$$T_v = \rho Q V_j \sin(\beta)$$

Equating equations (1) and (G.3), and solving for V_j gives

$$V_j = (\rho Q V_o + \frac{WD}{L})[\cos(\beta) + \frac{D}{L}\sin(\beta)]^{-1}$$

The minimum energy input to the jet occurs when V_j is at a minimum, or,

$$\frac{\partial V_j}{\partial \beta} = 0 \Rightarrow \frac{(\rho Q V_o + \frac{WD}{L})(\frac{D}{L}\cos(\beta) - \sin(\beta))}{(\cos(\beta) + \frac{D}{L}\sin(\beta))^2} = 0$$

$$\Rightarrow \beta = \mathrm{TAN}^{-1}[\frac{D}{L}] \tag{G.4}$$

which is the optimum angle for nozzle depression (refs. 4,6).

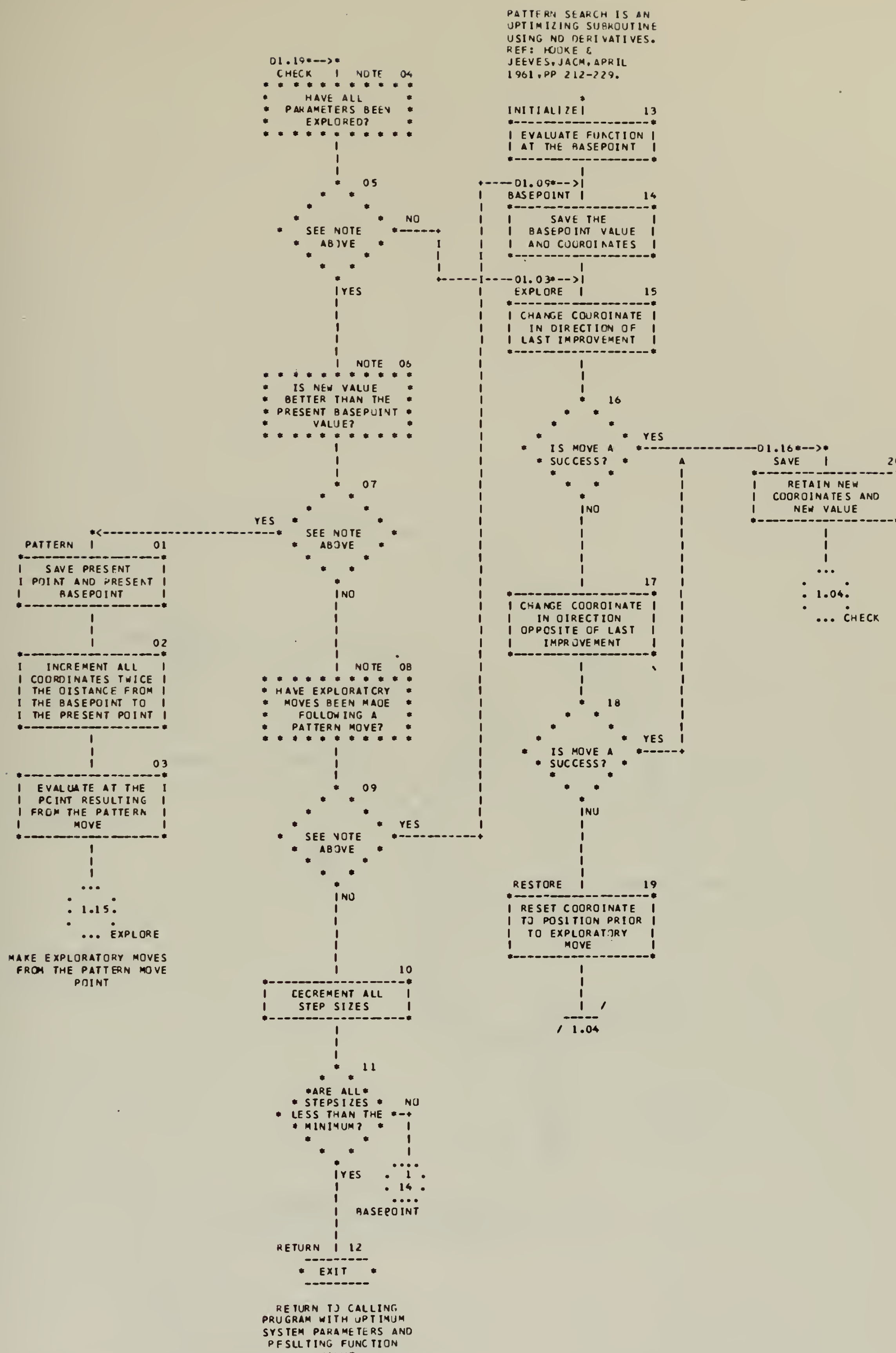

FIGURE 8 GENERALIZED PATTERN SEARCH FLOW DIAGRAM

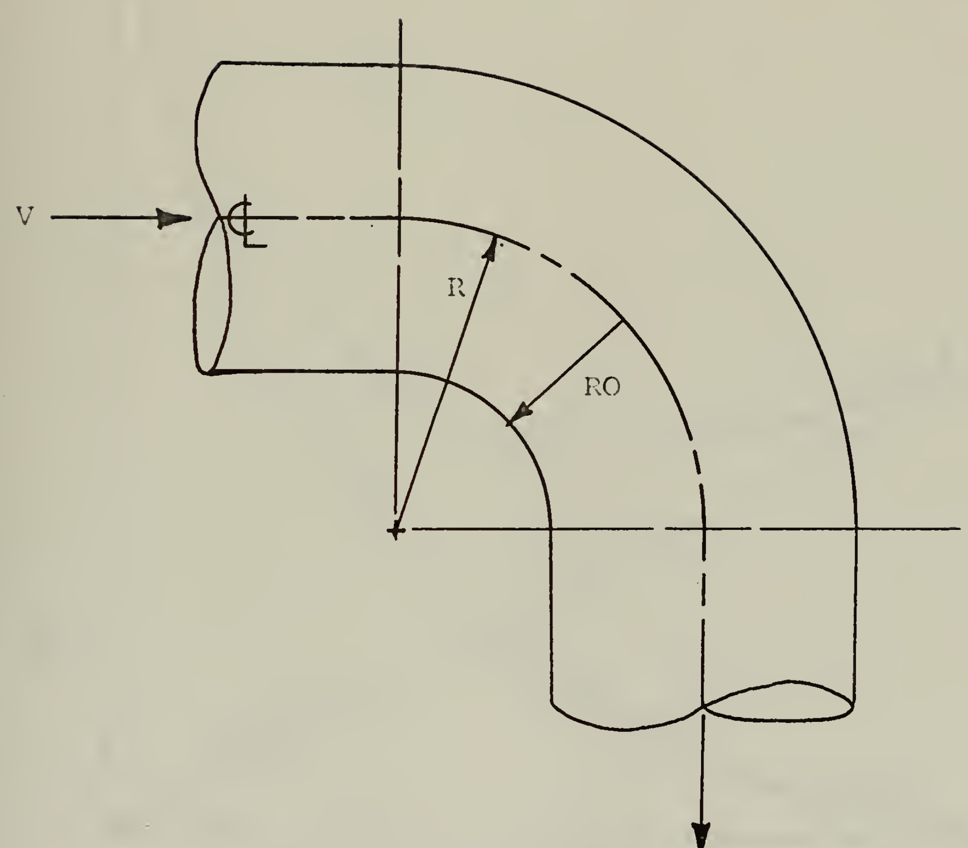

FIGURE 9. ELBOW

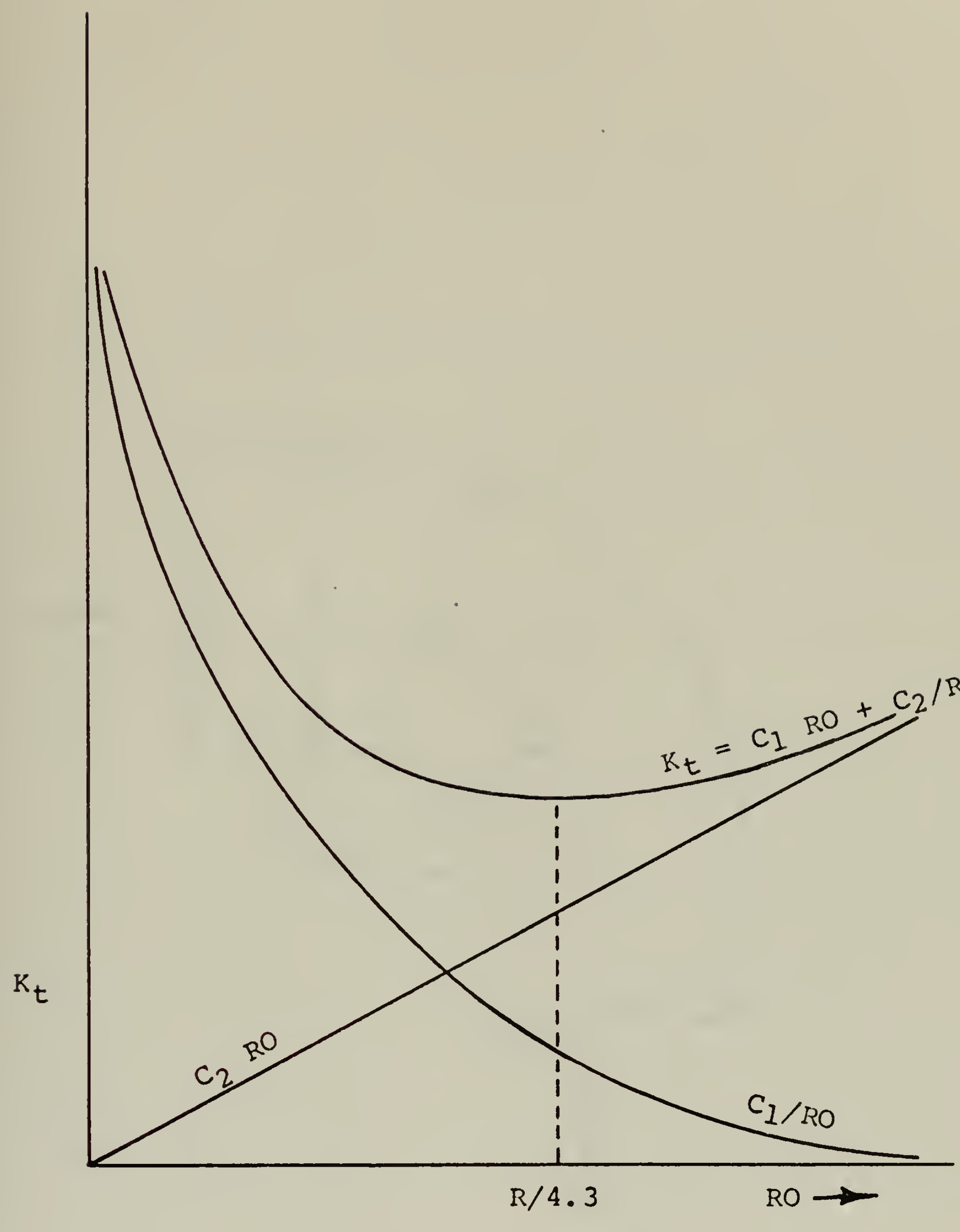

FIGURE 10 MINIMUM ELBOW LOSS COEFFICIENT

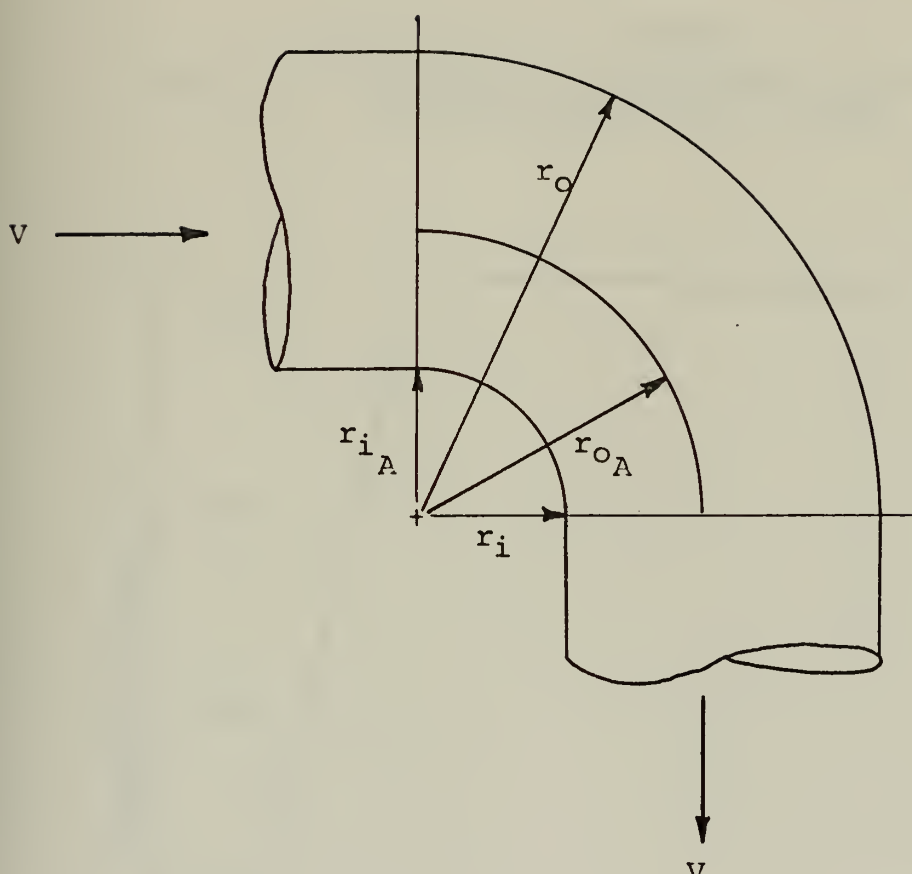

FIGURE 11 ELBOW WITH ONE SPLITTER

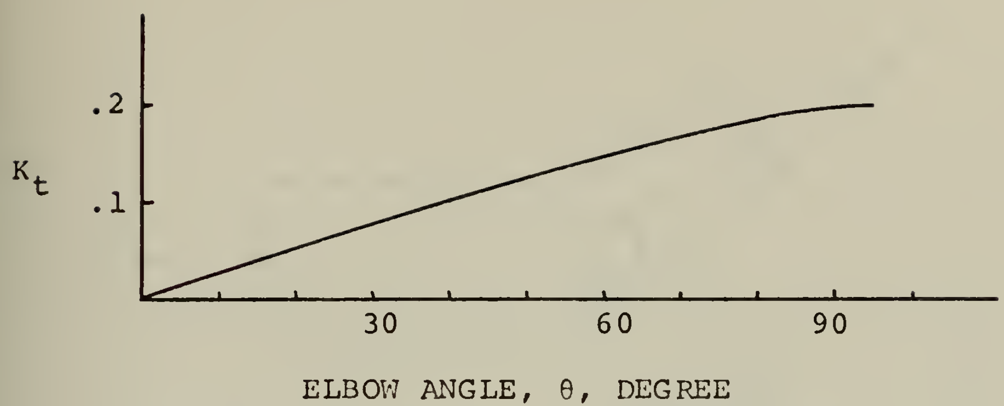

FIGURE 12 ELBOW LOSS COEFFICIENT WITH THIN, CIRCULAR-ARC TURNING VANES

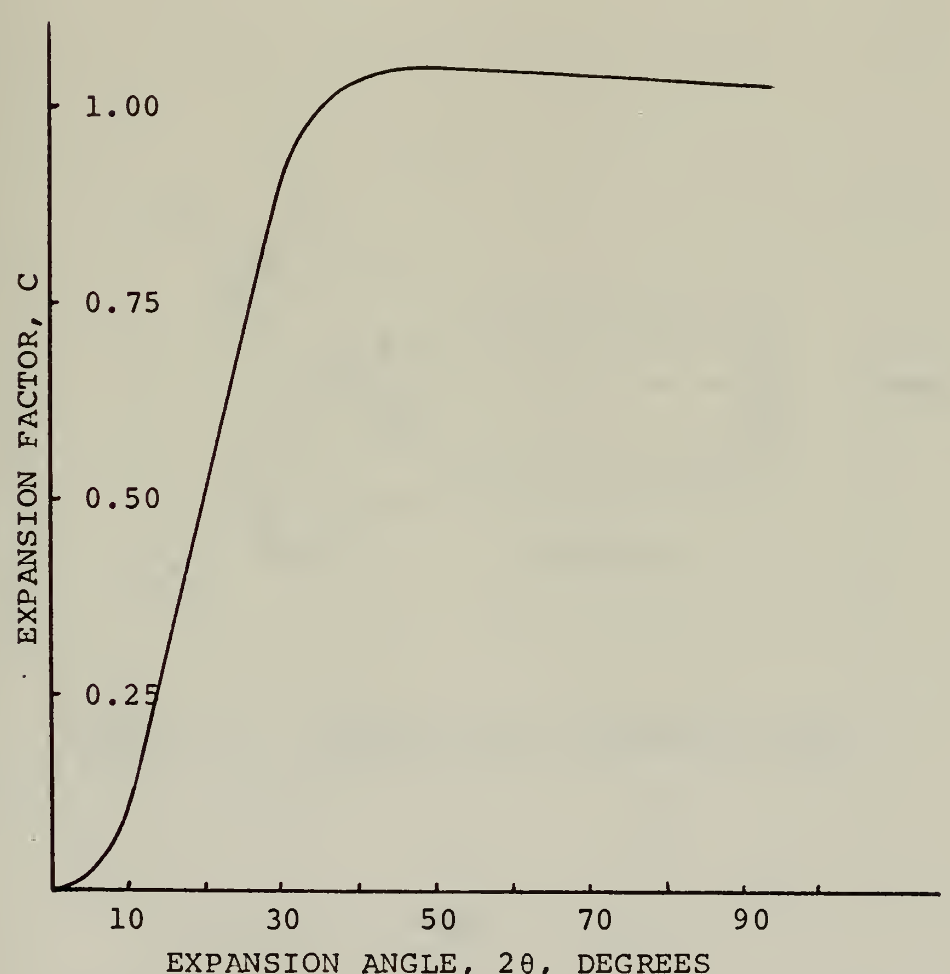

FIGURE 13 EXPANSION FACTOR FOR STRAIGHT WALLED, TWO- DIMENSIONAL DIFFUSER

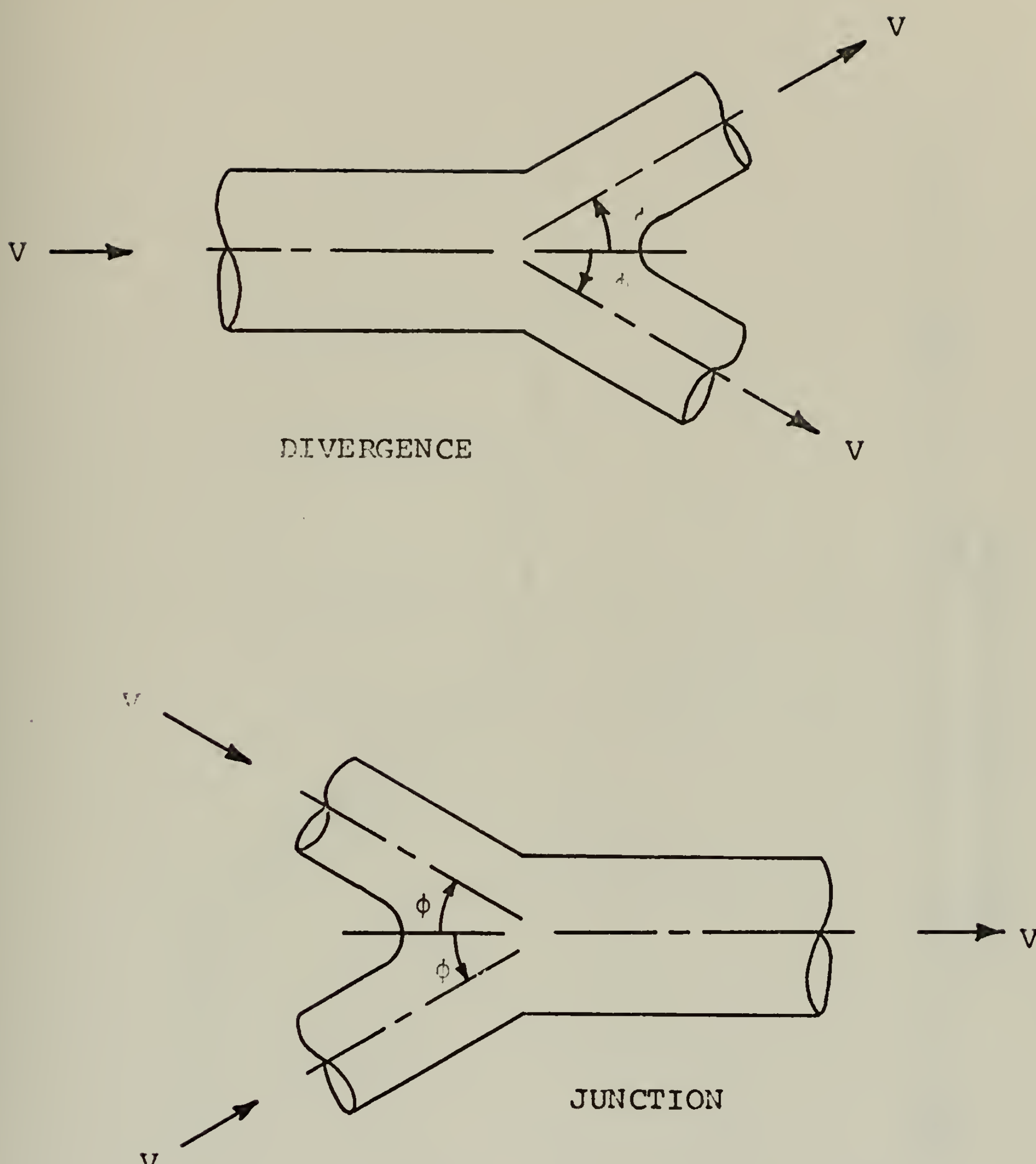

FIGURE 14 JUNCTION AND DIVERGING DUCTS

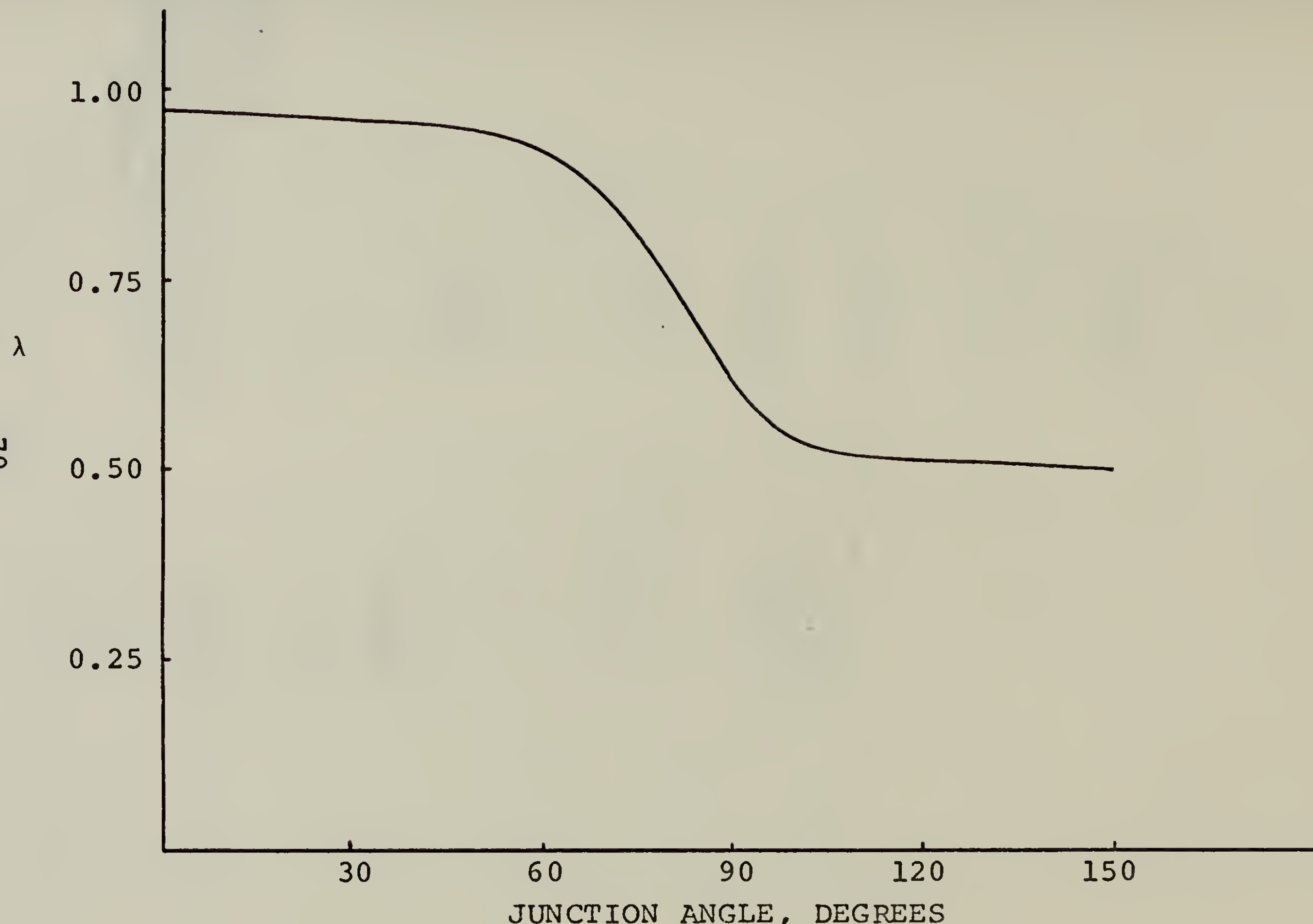

FIGURE 15 JUNCTION LOSS FACTOR, λ

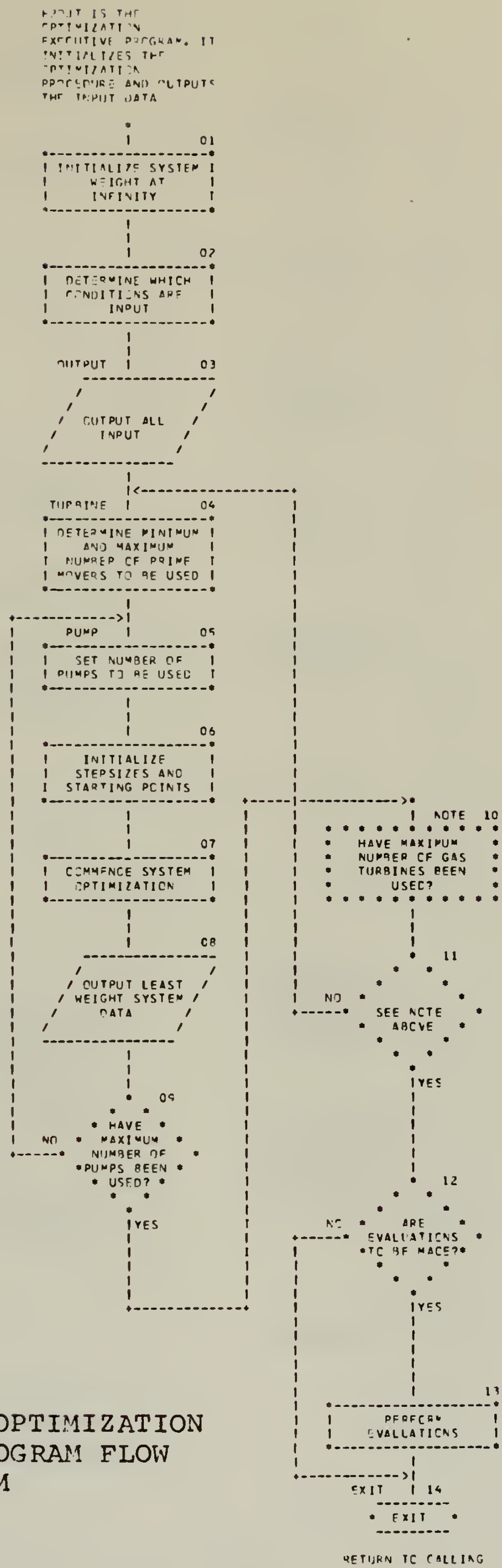

FIGURE 16

GENERALIZED OPTIMIZATION EXECUTIVE PROGRAM FLOW DIAGRAM

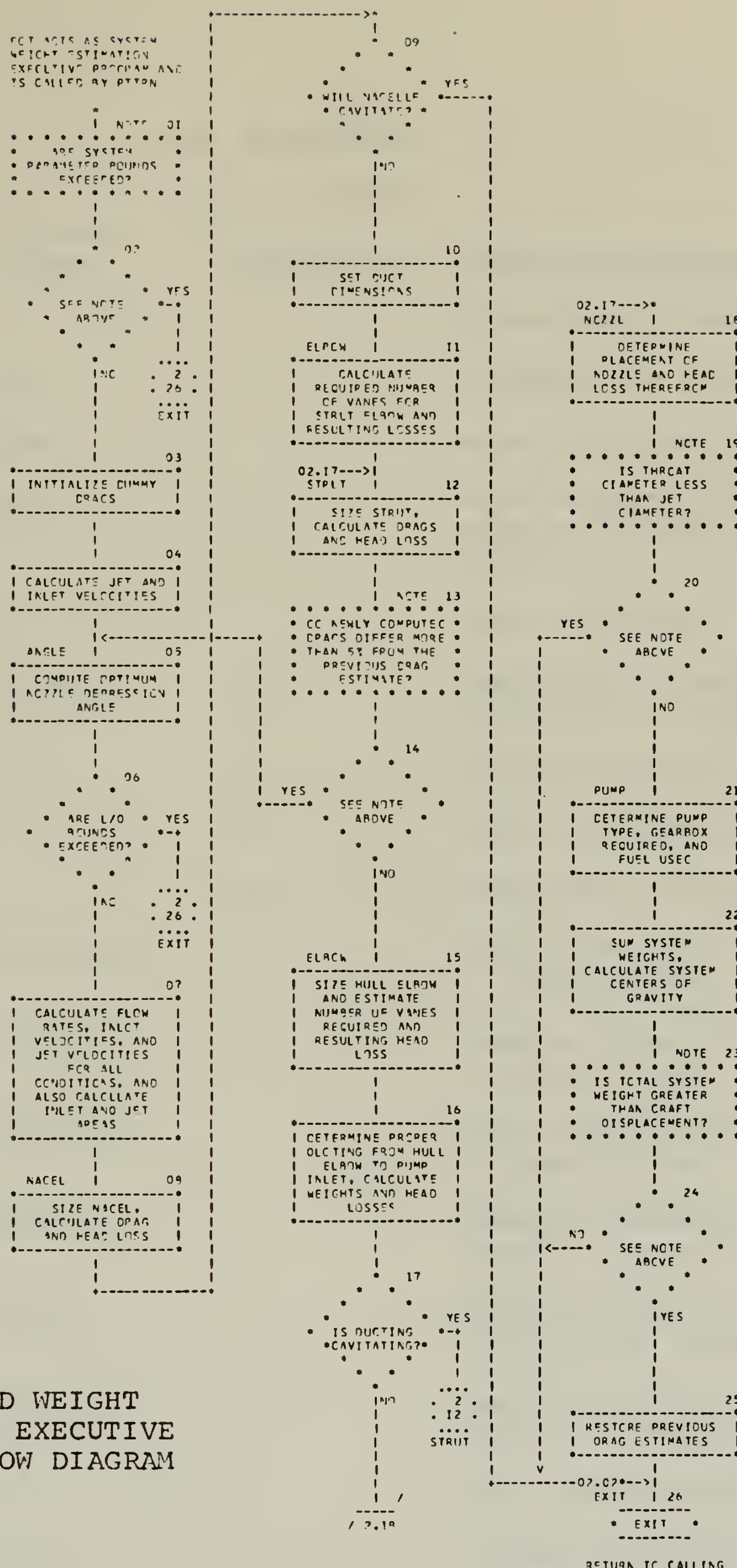

FIGURE 17

GENERALIZED WEIGHT ESTIMATION EXECUTIVE PROGRAM FLOW DIAGRAM

LIST OF SYMBOLS

USED IN COMMON

Label	Variable Name	Subscript	Description/Usage
PARMS			System parameters
	VJVO		Jet velocity ratio
	VIVO		Inlet velocity ratio
	DIDM		Inlet diameter to maximum nacelle diameter ratio
DRAG			Drag estimates
	TDRAG(I)	I	Total craft drag at condition I, pound force
		1	Cruise condition
		2	Take-off condition
		3-5	Evaluation conditions
	STRTD(I)		Strut drag at condition I, pound force
	POD(I)		Nacelle drag at condition I, pound force
	SPRAY(I)		Spray drag at condition I, pound force
	REST(I)		TDRAG(I)-SPRAY(I)-STRTD(I) -POD(I), pound force
	VO(I)		Craft velocity at condition I, foot per second
	TRIM(I)		Craft trim angle at condition I, degree
FLOW			Flow characteristics
	Q(I)		Volume flow rate at condition I, cubic foot per second

Label	Variable Name	Subscript	Description/Usage
	AIN		Inlet area, square foot
	AJET		Jet area, square foot
	AREA(ICOMP)		Ducting cross-sectional area at station ICOMP, square foot
	VJ(I)		Jet velocity at condition I, foot per second
	VI(I)		Inlet velocity at condition I, foot per second
ELBW			Elbow data
	XK(IELB)	IELB	Radius ratio of elbow IELB
		1	Strut elbow
		2	Hull elbow
		3	Pump elbow
		4	Divergence elbow
	RO(IELB)		Duct radius at elbow IELB, foot
	THATA(IELB)		Angle of bend of elbow IELB, degree
	WIDTH		Width of duct at elbow inlet
	DEPTH		Depth of duct at elbow inlet
	TYPE(3,ITYPE)		Contains name of elbow shape ITYPE
CHARS			System characteristics
	WGTS(LS,LC)		Weight of component LC, pound

Label	Variable Name	Subscript	Description/Usage
		LS	
		1	Structure
		2	Water (or fuel)
		LC	
		1	Nacelle
		2	Strut elbow
		3	Strut diffuser
		4	Hull elbow
		5	Athwartships length
		6	Pump elbow
		7	Transition piece
		8	Pump
		9	Nozzle
		10	Reduction gear
		11	Fuel
		12	Prime mover
		13	Lift from nozzle depression
		14	Total weight
		15	Spare location
	CGS(LG,LC)		Centers of gravity of component LC, excluding fuel, gearbox, or prime mover, foot
		LG	
		1	Structure vertical center gravity (from keel)

Label	Variable Name	Subscript	Description/Usage
		2	Structure longitudinal center of gravity (from transom)
		3	Water vertical center of gravity, (from keel)
		4	Water longitudinal center of gravity, (from transom)
	DELH(I,ICOMP)		Total head loss up to and including component ICOMP at condition I, foot
		ICOMP	Same as defined except
		8	Nozzle head loss only
		9	Total system head loss (including elevation), DELH(I,9)=DELH(I,8)+ DELH (I,7)
		10-15	Spare locations
	CGSX		Total longitudinal center of gravity of system excluding gearbox, prime mover and fuel, from transom, foot
	CGSZ		Total vertical center of gravity of system excluding gearbox, prime mover and fuel, from keel, foot
H2O			Sea water (3.5% salinity) properties
	TEMP		Temperature, degree Fahrenheit
	PV		Vapor head, foot
	RHOW		Density, pound force second squared per foot to the fourth

Label	Variable Name	Subscript	Description/Usage
	GNU		Viscosity, foot squared per second
	HA		Atmospheric head, foot
TOLER			
	DELTA		Check for optimum system
PSUB			Pump system
	GERAT(NSTG)		Gear ratio required for pump NSTG
	SHP(I,NSTG)		Shaft horsepower required at condition I for pump NSTG, horsepower
	RPM(I,NSTG)		Axial speed of pump NSTG at condition I, revolution per minute
	PERF(L,IENGN)		Prime mover IENGN Characteristics (L)
		L	
		1	Maximum normal horsepower at design speed, horsepower
		2	Maximum intermittent horsepower at design speed, horsepower
		3	Specific fuel consumption (SFC) at design speed and maximum normal horsepower, pound fuel per horsepower hour
		4	Design speed, RPM
		5	Prime mover weight, without auxiliaries, pound
	ETAP(I,NSTG)		Efficiency of pump NSTG at condition I

Label	Variable Name	Subscript	Description/Usage
		I	Same as defined except
		7	Reduction gear
		6,8	Spare locations
SHIP			Craft characteristics
	DISP		Craft displacement, pound
	RANGE		Endurance, nautical mile
	BEAM		Beam, foot
	HS		Depth of submergence of foil, foot
	HE		Height of pump centerline above keel, foot
	HCL		Height of pump centerline above mean water, foot
	XLS		Distance of centerline of strut root from transom, foot
	XLPE		Distance of pump exit from transom, foot
	XLP		Length of pump, foot
NACELLE			Nacelle characteristics
	DRAT		Diameter ratio, DI/DM
	DM		Maximum external diameter, foot
	AI		Inlet area per nacelle, square foot
	AIAUX		Auxiliary inlet area per nacelle, square foot
	ELEXT		Length of forebody, foot
	ELENT		Length of lip, foot

Label	Variable Name	Subscript	Description/Usage
	ELAUX		Length due to auxiliary inlet, foot
	ELDIF		Length of diffuser, foot
	ELN		Length of nacelle, foot
CONST			Constants
	PI		3.14159265
	G		Acceleration of gravity, 32.174,foot per second squared
	RHOD		Density of steel, 480, pound per cubic foot
STRTC			Strut characteristics
	TC		Thickness to chord ratio
	T		Thickness at root, foot
	C		Chord at root, foot
	T1		Thickness at tip, foot
	C1		Chord at tip, foot
	CFM		Chord at flying water-line, foot
INDEX			Indices for program control
	IEVAL		Design/evaluation index
		<0	Evaluate at |IEVAL| points, no design
		=0	Design at cruise and take-off conditions only
		>0	Design at cruise and take-off conditions and evaluate at |IEVAL| points

[illegible]

Label	Variable Name	Subscript	Description/Usage
	IEQPT		
		=0	No equipments or configuration entered; total system design/evaluation
		>0	Specific equipments or configuration entered (not yet implemented into program)
	ISTRT		Initial program condition
		1	Design and/or evaluate
		3	Evaluate only
	NUMB		Final program condition
		2	Design only
		2+|IEVAL|	Design and/or evaluate
	IENGN		Prime mover type
		1	TF 35
		2	TF 40
		3	Proteus, 1500 rpm
		4	Proteus, 1000 rpm
		5	Tyne 1A
		6	Tyne 1C
		7	FT12A
		8	LM 1500
		9	LM 2500
		10	FT4A-2C
		11	FT4A-12
		12	FT4C-2

Label	Variable Name	Subscript	Description/Usage
	ITYPE		Elbow shape
		1	Ellipse
		2	Circle
		3	Rectangle
		4	Square
	ICOMP		Component index
		1	Nacelle outlet
		2	Strut elbow
		3	Strut diffuser exit
		4	Hull elbow
		5	Athwartships length
		6	Pump elbow
		7	Transition piece
		8	Pump inlet
		9	Nozzle throat
	NPUMP		Number of pumps
	NGT		Number of gas turbines
ITABL			Interpolation parameters
CDRAG			Computed drags
	CSTRT(I)		Computed strut drag at condition I, pound force
	CPOD(I)		Computed nacelle drag at condition I, pound force
	CSPRY(I)		Computed spray drag at condition I, pound force
WEGT			Pump, gear and fuel weights

Label	Variable Name	Subscript	Description/Usage
	XWD(NSTG)		Pump NSTG dry weight, pound
	XWW(NSTG)		Pump NSTG wet weight, pound
	XWG(NSTG)		Gearbox weight associated with pump NSTG, pound
	XWF(NSTG)		Fuel weight associated with pump NSTG, pound
PUMM			Pump characteristics
	QQ(I)		Flow rate per pump at condition I, cubic foot per second
	D1S(NSTG)		Inlet tip diameter of pump NSTG, foot
	D2S(NSTG)		Exit tip diameter of pump NSTG, foot
	XNS(NSTG)		Specific speed of pump NSTG, cfs units
	SM(NSTG)		Suction specific speed of pump NSTG, cfs units
	PLP(NSTG)		Length of pump NSTG, foot
	NSTG		Indicator of pump type
		1	Axial pump with single inducer impeller
		2	Axial pump with inducer and one impeller stage
		3	Axial pump with inducer and two impeller stages
		4	Centrifugal pump with maximum of ten parallel double suction impellers
		5	Spare location

[illegible]

Label	Variable Name	Subscript	Description/Usage
	SHI(NSTG)		Head coefficient of pump NSTG
	XIM		Number of parallel double suction impellers for centrifugal pump
			Number of impellers, not including inducer, for centrifugal pump
HEAD			Pump flow characteristics
	HPP(I)		Pump head at condition I, foot
	HSV(I)		Net positive suction head at condition I, foot
	THOM(I)		Thoma's cavitation index at condition I
	PHI(NSTG)		Flow coefficient of pump NSTG
	WF		Working variable for fuel weight, pound
	WG		Working variable for gear weight, pound
*****			Unlabeled common variables
	IFUEL		Logical variable for fuel calculation
		.TRUE.	Make fuel calculation
		.FALSE.	Do not make fuel calculation

VARIABLES USED IN H2OJT
NOT IN COMMON

Variable	Description
PARM(3)	Working system parameters
ENGN(3,IENGN)	Contains name of engine IENGN for output
EHP(I)	Effective horsepower at condition I, horsepower
DEL(3)	Initial step sizes of system parameters
DELMIN(3)	Minimum step sizes of system parameters
VK(I)	Craft speed at condition I, knot
IPRNT	Print data set reference number
DISPL	Craft displacement, long ton
IN	Estimate of minimum number of gas turbines required to power craft
MAX	Estimate of maximum number of gas turbines needed to power craft
XJ	Working variable for number of gas turbines
IK	Working variable for craft condition I
IL	Working variable for IN
KM	Minimum number of pumps to be used for XJ gas turbines
K1	Maximum number of pumps to be used for XJ gas turbines
WEIGT	Propulsion system weight, long ton
IM	Working variable for prime mover characteristic L
DISPL	Craft displacement, long ton
I	Index for do loops
IJ	Working variable for check on power adequacy
J	Index for do loop

Variable	Description
ISAVE	Working variable for MAX
N	Working variable for output of prime mover type
XMIN	Factor for minimum acceptable prime mover SHP operation
MK	Working variable for prime mover characteristic L

LIST OF VARIABLES USED IN FCT
NOT IN COMMON

Variable	Description
APOD(I)	Difference between present and previous nacelle drag calculations at condition I, pound force
ASTRT(I)	Difference between present and previous strut drag calculations at condition I, pound force
ASPRY(I)	Difference between present and previous spray drag calculations at condition I, pound force
C(I)	Margin factor for thrust at condition I
TSUM	Working variable for propulsion system weight, pound
DSIG	Working variable for SIGMA
TOTAL	Total head less vapor head, foot
SIGMA	Head above vapor head, foot
SUMZ	Working variable for moment in vertical plane, due to weights, foot pound force
SUMX	Working variable for moment in longitudinal plane due to weights, foot pound force
SUM	Working variable for system weights, pound
ZSUM	Total moment in vertical plane due to weights, foot pound force
XSUM	Total moment in longitudinal plane due to weights, foot pound force
SPD	Working variable for jet velocity calculation, foot per second
J	Working variable for NUMB
JDRAG	Indicator of acceptable drag accuracy
1	New drag calculation is within 5% of previous

Variable		Description
		calculation
	2	New drag calculation is greater than 5% of previous calculation, redesign strut and nacelle
ANGLE		Optimum nozzle depression angle, radian
COEF		Factor for nacelle drag calculation
	0	Strut must be resized due to cavitation
	1	Use nacelle design
KOUNT		Working variable for craft condition I
I		Craft condition
PARM(K)		Working variable for system parameters
	K	
	1	VJVO
	2	VIVO
DDRAG(I)		Previous acceptable total drag calculation at condition I, pound force
DSPRY(I)		Previous acceptable spray drag calculation at condition I, pound force
DSTRT(I)		Previous acceptable strut drag calculation at condition I, pound force
DPOD(I)		Previous acceptable nacelle drag calculation at condition I, pound force

[illegible]

LIST OF VARIABLES USED IN NACEL NOT IN COMMON

Variable	Description
ZK	Percentage of auxiliary inlet area permitting flow
SPO	Static pressure at inlet, pound per square foot
PVP	Vapor pressure, pound per square foot
SIGTV	Incipient turning vane cavitation number, referenced to diffuser exit velocity
JNUMB	Working variable for NUMB
I	Craft condition, also index for do loops
CPEX	Peak external pressure coefficient
K	Working index for do loop for ELEXT/DM values
J	Working index for do loop for VIVO values
XD	Length of forebody to maximum diameter ratio, ELEXT/DM
DIDMX	Maximum permissible diameter ratio
QI	Flow rate per strut, cubic foot per second
DI	Nacelle inlet diameter, foot
CPIN	Peak internal pressure coefficient
QIN	Take-off flow rate per nacelle through inlet, cubic foot per second
QC	Take-off flow rate per nacelle, total, cubic foot per second
QAUX	Auxiliary flow rate required to avoid cavitation, cubic foot per second
KDEX	Counter for iterations on diffuser length
VR	Velocity ratio at take-off condition, based on flow through inlet

Variable	Description
VI2	Inlet velocity at take-off condition, based on flow through inlet
PRL2	Pressure recovery coefficient of lip at take-off
PTI	Inlet stagnation pressure immediately aft of lip at take-off, pound per square foot
SPI	Inlet static pressure immediately aft of lip at take-off, pound per square foot
VIAUX	Inlet velocity in auxiliary inlet, foot per second
PRAUX	Pressure recovery of auxiliary inlet
PTAUX	Stagnation pressure inside auxiliary inlet, pound per square foot
DYP	Net dynamic pressure immediately aft of lip, pound per square foot
PC	Average inlet stagnation pressure of combined flow, pound per square foot
QDIF	Working variable for diffuser flow rate, cubic foot per second
PHI	Equivalent angle of forebody, radian
PHS	Sine of equivalent angle of forebody
X	Length of auxiliary inlet, foot
D2	Diffuser exit diameter, foot
D1	Inlet diameter, foot
ELMAX	Maximum permissible length of diffuser, foot
ELMIN	Minimum permissible length of diffuser, foot
II	Working variable for craft condition I
EL	Working variable for diffuser length, foot
DEL	Working variable for change in diffuser length, foot

Variable	Description
ELD	Working variable for nacelle length, foot
ELL	Working variable for nacelle length, foot
ELFAC	Working variable for excess in nacelle length due to diffuser, foot
DDM	Average diffuser diameter, foot
XKT	Form loss coefficient of diffuser
REL	Reynolds number, based on nacelle length
RED	Reynolds number, based on inlet diameter
DL	Ratio of maximum external diameter to nacelle length
CDRG	Computed drag coefficient
ANGL	Equivalent half angle of diffuser, degree
CDIF	Diffuser expansion factor
POW	Power loss due to drag and duct loss of diffuser, horsepower
POWI	Previous power loss calculation for diffuser length, horsepower
EM	Factor in wetted surface calculation
AEXN	Wetted surface area, square foot
REND	Reynolds number, based on inlet diameter
DDIF	Total pressure loss in diffuser, pound per square foot
PLOSS	Total pressure loss in nacelle, pound per square foot
VAOUT	Average exit velocity, foot per second
SQUAR	Factor in critical velocity calculation
VCRIT	Critical velocity in strut elbow, foot per second

Variable	Description
VMAX	Maximum velocity at nacelle exit, foot per second
RENL	Reynolds number, based on nacelle length
NL(2)	Interpolation parameters
ML(2)	Interpolation parameters
KL(2)	Interpolation parameters
JL(2)	Interpolation parameters
IL(2)	Interpolation parameters
VRT(6)	Data array of velocity ratios
XDT(10)	Tabulated forebody length to inlet diameter ratios
PRLT(6)	Tabulated lip pressure recovery coefficients
SIGI(I)	Free stream cavitation index at condition I
PTO(I)	Stagnation pressure at craft condition I, pound per square foot
XDTT(J)	Tabulated ELEXT/DM ratios for trim angle J
CDUMX(K)	Dummy array of peak pressure coefficients for VIVO K
CDUMY(L)	Dummy array of velocity ratios for ELEXT/DM L
CD(I)	Drag coefficient at craft condition I
DIDMT(J)	Tabulated DI/DM values for ELEXT/DM J
VRTT(J)	Dummy array of velocity ratios for angle of attack (J), internal
DLIP(I)	Lip loss coefficient at craft condition I
QO(I)	Free stream dynamic pressure at craft condition I, pound per square foot
VELR(I)	Inlet velocity ratio at craft condition I

Variable	Description
VRTEX(I)	Same as VRTT(I) but external
VRMAX(I)	Maximum permissible velocity ratio at craft condition I
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

VARIABLES USED IN ELBOW NOT IN COMMON

Variable	Description
SHAPE(3,ITYPE)	Contains name of shape ITYPE
THETA(J)	Data array of elbow angles
XLOSS(J)	Data array of elbow loss coefficients with thin, circular arc turning vanes
ROA(10)	Outside radius of splitters, foot
RE	Reynolds number of duct
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number
CORR	Function statement, calculates head loss correction factor for different Reynolds numbers
REMAX	Maximum Reynolds number permitted for splitter loss equation
KOUNT	Working variable for craft condition I
IELB	Index indicating which elbow is being designed/evaluated
1	Strut
2	Hull
3	Pump
4	Divergence
FACTR	Factor used in splitter loss calculation
RIN	Inside radius of bend, foot
ROUT	Outside radius of bend, foot
RATIO	Desired radius ratio, 4.3
XN	Number of subdivided elbows required to achieve RATIO=4.3

Variable	Description
N	Number of subdivided elbows used
N1	Number of splitters corresponding to N
SUM	Working variable of sum of head times subdivided elbow area, foot cubed
RIA	Inside radius of subdivided elbow, foot
V	Average velocity, foot per second
HGT	Height of subdivided elbow, foot
AA	Equivalent cross-sectional area of subdivided elbow based on HGT, square foot
RAD	Equivalent radius of subdivided elbow, foot
XCORR	Ratio of head loss correction factors for differing Reynolds numbers
XKT	Head loss coefficient of subdivided elbow
DIAM	Equivalent diameter, foot
VOLV	Volume of splitters, cubic foot
VOL	Volume of splitters and elbow structure, cubic foot
AREA1	Duct area per elbow, square foot
IJ	Working variable for shape determination
IK	Working variable for shape determination
I	Working variable for number of subdivided elbows N
RATEO	Ratio of inside radius to outside radius of subdivided elbows
HEAD	Average head loss in elbow, foot

[illegible]

LIST OF VARIABLES USED IN STRUT NOT IN COMMON

Variable	Description
THET2	Array of data of equivalent angle of diffuser, degree
EXPAN	Array of data of expansion coefficient
ARATO	Area ratio of strut diffuser
VL	Local maximum velocity, external, foot per second
SIGMA	Local cavitation number, external
CM	Mean chord, foot
DEIN	Strut inlet equivalent diameter, foot
WIDE	Width of duct at strut exit, foot
DEOUT	Strut exit equivalent diameter, foot
DEAVE	Average equivalent diameter, foot
STRT	Vertical strut length, foot
XLONG	Actual strut length, foot
STAN	Arctangent of equivalent diffuser angle
THETA	Equivalent angle of diffuser, 2θ, degree
ECOEF	Diffuser expansion factor
FORML	Diffuser expansion loss coefficient
VELIN	Average inlet velocity, foot per second
VLOUT	Average exit velocity, foot per second
RES	Strut Reynolds number, based on mean chord
CDS	Strut drag coefficient
CDSP	Spray drag coefficient
RE	Duct Reynolds number, based on inlet velocity

Variable	Description
PIPEL	Duct friction loss coefficient
TOTAL	Total loss coefficient
HEAD	Head loss of diffuser, foot
KOUNT	Working variable for craft condition I
HGT	Elevation of strut, foot
CGWS	Vertical center of gravity of duct, foot

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

LIST OF VARIABLES USED IN JUNCT
NOT IN COMMON

Variable	Description
ALPHA	Assumed junction angle of 0^{o}, degree
DIAM	Duct diameter, foot
FRCTL	Friction loss coefficient for athwartships length
KOUNT	Working variable for craft condition I
AJCT	Length of fore and aft ducting to pump inlet, foot
FRCTJ	Friction loss coefficient for junction
XLAMD	Working variable for AMIXL calculation
FLONG	Length of athwartships ducting, foot
AJCTL	Total loss coefficient of junction
AMIXL	Mixing loss coefficient of junction
V	Average velocity, foot per second
XPUMP	Number of gas turbines + 1
RE	Reynolds number of duct
BETA(J)	Data array of junction angles, degree
ALAMD(J)	Data array of mixing loss coefficient corresponding to BETA(J)
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

LIST OF VARIABLES USED IN PIPE NOT IN COMMON

Variable	Description
KOUNT	Working variable for craft condition I
V	Average velocity, foot per second
DIAM	Duct diameter, foot
RE	Reynolds number of duct
APIPE	Length of fore and aft pipe to pump inlet, foot
FRCTL	Friction loss coefficient for athwartships length
XPUMP	Number of gas turbines
XKT	Friction loss coefficient of fore and aft length
XLONG	Length of athwartships pipe, foot
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

LIST OF VARIABLES USED IN DIVRG
NOT IN COMMON

Variable	Description
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number
KOUNT	Working variable for craft condition I
RE	Reynolds number of duct
DIVL	Divergence loss coefficient, not including friction
DWGT1	Duct weight of divergence angle, pound
DWGT2	Duct weight of divergence length, pound
DWGT3	Duct weight of pump inlet angle, pound
WWGT1	Water weight of divergence angle, pound
WWGT2	Water weight of divergence length, pound
WWGT3	Water weight of pump inlet angle, pound
CGWX1	Longitudinal center of gravity of divergence angle, from transom, foot
CGWX2	Longitudinal center of gravity of divergence length, from transom, foot
CGWX3	Longitudinal center of gravity of pump inlet angle, from transom, foot
DIAM	Duct diameter, foot
FRCTL	Friction loss coefficient for athwartships length
DIVLC	Total divergence loss coefficient
XPUMP	Number of gas turbines + 1
ANGLE	Divergence angle, also pump inlet angle, radian
HEADL	Total divergence head loss, foot
FLONG	Athwartships length, foot

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

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[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Variable	Description
XLONG	Fore and aft length, foot
V	Average velocity, foot per second
ADIV	Divergence length, ADIV = XLONG/COS(ANGLE),foot
THETA(J)	Data array of divergence angles, degree
COEF(J)	Data array of divergence loss coefficients without friction, corresponding to THETA(J)

LIST OF VARIABLES USED IN NOZZL
NOT IN COMMON

Variable	Description
KOUNT	Working variable for craft condition I
XLPS	Dummy nozzle length, foot
XFAC	Check on whether nozzle exits through bottom or stern
XPUMP	Number of pumps
ANOZ	Optimum nozzle depression angle, radian
XLNOZ	Nozzle length, foot
DT	Nozzle throat diameter, foot
DJ	Nozzle jet diameter, foot
XCORR	Nozzle head loss factor
RE	Reynolds number, based on average diameter and velocity
AREA1	Throat pipe area, square foot
AJET1	Jet pipe area, square foot
QQ	Flow rate per nozzle, cubic foot per second
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

LIST OF VARIABLES USED IN PUMP
NOT IN COMMON

Variable	Description
K	Cruise condition indicator
J	Take-off condition indicator
I	Index for do loops
XPUMP	Number of pumps
THOMI	Lower limit of Thoma's criterion for single inducer axial pump
DRAT	Hub to tip diameter ratio
XXLP	Factor for pump length
CW	Weight coefficient
QX	Ratio of cruise flow rate to take-off flow rate
CA	Factor for RPM calculation
CB	Factor for RPM calculation
HX	Ratio of design pump head to off design head
RX	Ratio of design to off design pump RPM
PHRAT	Ratio of off design to design flow coefficients
XNGT	Number of gas turbines
ETAPP	Product of pump and gearbox efficiencies
HP	Inducer head for one and two stage axial pump designs, foot
THOMS	Thoma's cavitation criterion for inlet to axial stage
HHP	Axial stage pump head, foot
BETA2	Exit blade angle, radian

Variable	Description
XNNS	Non-dimensional specific speed
BD	Impeller exit width ratio
CC	Factor in flow coefficient calculation
AA	Factor in flow coefficient calculation
IMPL	Maximum number of impellers permitted for centrifugal pump, = 10
M	Working variable for number of centrifugal pump impellers
N	Working variable for NSTG
PC(K,J)	Inducer head curve coefficients
PCA(K,J)	Inducer plus axial stage head curve coefficients
PCC(K,J)	Centrifugal pump head curve coefficients
XRPM(M)	Working variable for off design RPM of centrifugal pump with M impellers, RPM
XD1(M)	Working variable for inlet tip diameter, D1S, foot
XD2(M)	Working variable for exit tip diameter, D2S, foot
RPK(M)	Working variable for design RPM of centrifugal pump with M impellers, square foot
XPUP(M)	Working variable for centrifugal pump area with M impellers, foot squared
YLP(M)	Working variable for centrifugal pump length with M impellers, foot
XERAT(M)	Working variable for gear ratio required for centrifugal pump with M impellers
APUP(NSTG)	Inlet area of pump NSTG, square foot
WRAT(NSTG)	Weight ratio of pump NSTG, including pump dry and wet weight, gearbox and fuel

Variable	Description
WD(M)	Working variable for XWD(NSTG) for centrifugal pump with M impellers
WW(M)	Working variable for XWW(NSTG) for centrifugal pump with M impellers
WWG(M)	Working variable for XWG(NSTG) for centrifugal pump with M impellers

LIST OF VARIABLES USED IN FUEL NOT IN COMMON

Variables	Description
CFS	Constant for SFC calculation
CA	Cruise condition drag to lift ratio
CD	1 + total system head loss coefficient, based on jet velocity
N	Number of intervals endurance is divided into + 1
XN	Number of intervals endurance is divided into
TI	Time to cover one range interval at constant VO(1), hour
IJK	Index for shifting SFC curves
XJ	Factor to convert SFC if SHP is less than 70% of design SHP
I	Working index for N
H	Head required, foot
SHPP	Total thrust required, horsepower
SHNG	Total thrust required per engine, horsepower
M	Working index for N
WT(ITIME)	Weight of fuel used in time increment ITIME, pound
DIS(ITIME)	Displacement at time increment ITIME, pound
VJJ(ITIME)	Jet velocity at time increment ITIME, foot per second

LIST OF VARIABLES USED IN PTTRN
NOT IN COMMON

Variable	Description
PSI(N)	Current basepoint coordinate of parameter N
THETA(N)	Previous basepoint coordinate of parameter N
PHI(N)	Present exploratory point coordinate of parameter N
DEL(N)	Current step size of parameter N
DELMIN(N)	Minimum step size of parameter N
DIR(N)	Last successful direction of parameter N
SAVE(N)	Working variable for PHI(N)
S	Working variable for function value
SPHI	Working variable for function value at PHI coordinates
SPSI	Current best function value at PSI coordinates
NUMB	Counter for minimum step size check
RHO	Step size change factor
ICALL	Indicator of current point move
K	Index for do loop
I	Index for do loop
N	Number of parameters of search
SIGN(N)	Directed step size of parameter N

LIST OF VARIABLES USED IN OUTPUT NOT IN COMMON

Variable	Description
IPRNT	Print data set reference number
J	Working variable for condition I
SUM	Total duct head loss, excluding elevation, foot
I	Index for do loop
DRATO	Strut diffuser area ratio
IK	Index for number of elbows in system
XNGT	Number of gas turbines
K	Index for do loop
L	Index for implied do loop in output statement
LL	Working variable to point to correct head loss for output
KLL	Working variable to point to correct format statement for head loss output
M	Index for implied do loop in output statement
NIMP	Number of impellers in pump
TFM	Strut thickness at flying waterline, foot
WTRAT	Total propulsion system weight ratio
WRATF	Propulsion system weight ratio, excluding fuel
ENGN(IENGN)	Contains name of engine IENGN
VJRAT(I)	Jet velocity ratio at craft condition I
VIRAT(I)	Inlet velocity ratio at craft condition I
HEADL(I,ICOMP)	Head loss of component ICOMP at craft condition I
CONDS(2,I)	Label for craft condition I

Variable	Description
ELBWS(2,IK)	Label for elbow IK
PC(I)	Propulsive coefficient at craft condition I
LABEL(5,M)	Labels for output

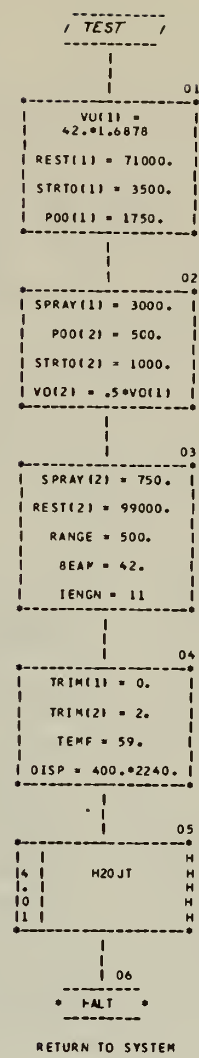

FIGURE 18 TEST PROGRAM FLOW DIAGRAM

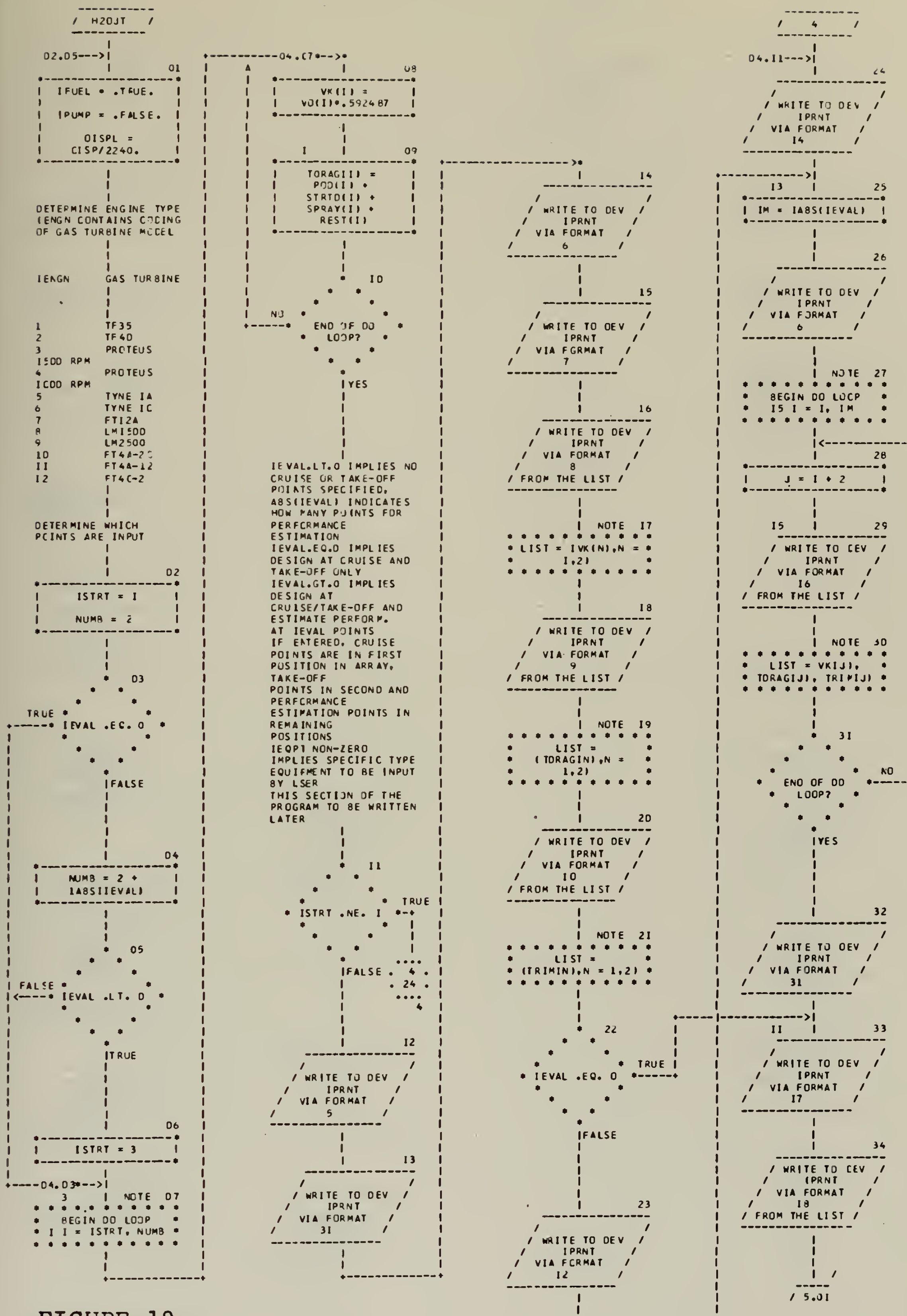

FIGURE 19

SUBROUTINE H2OJT FLOW DIAGRAM

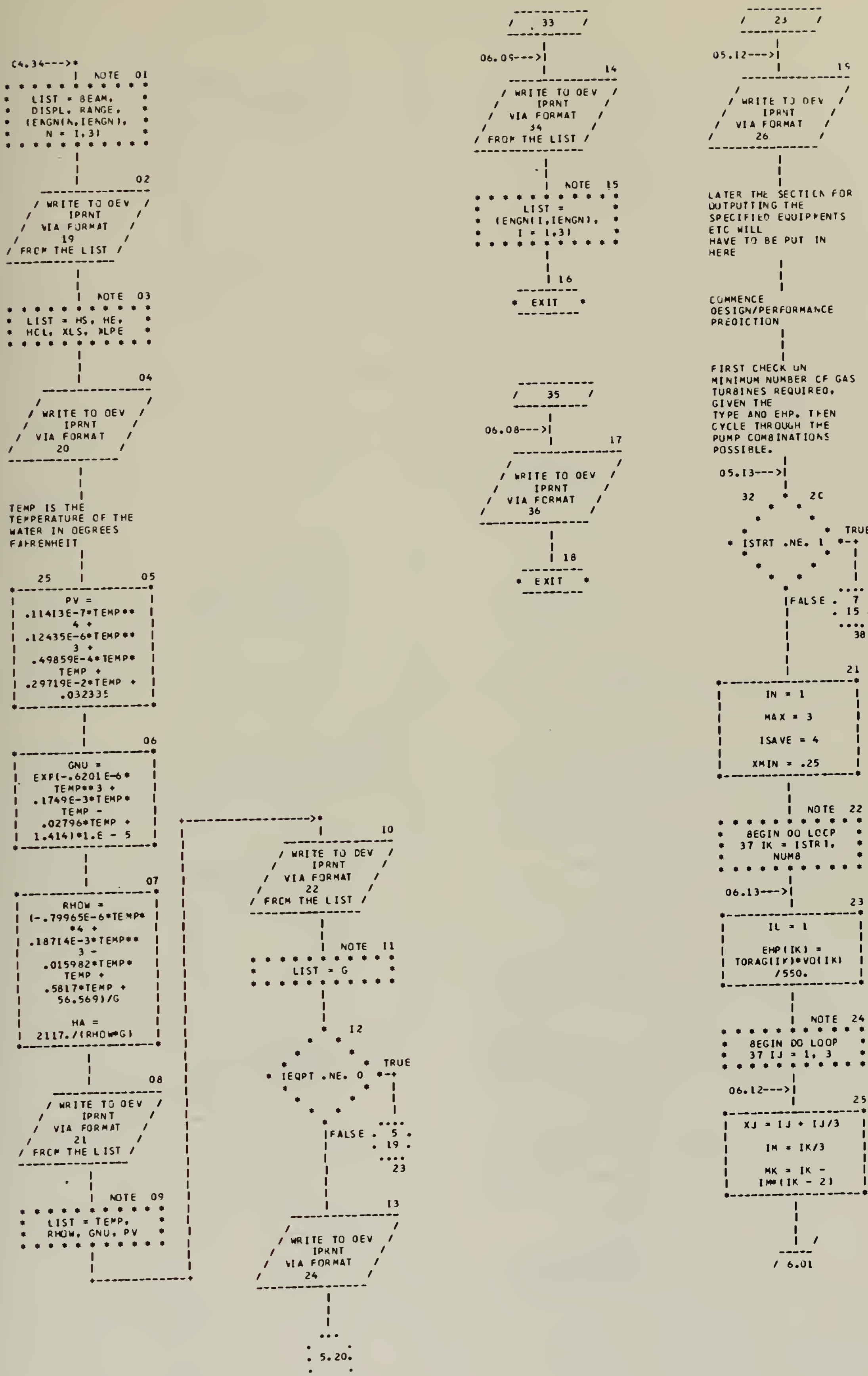

FIGURE 19 SUBROUTINE H2OJT FLOW DIAGRAM (CONT.)

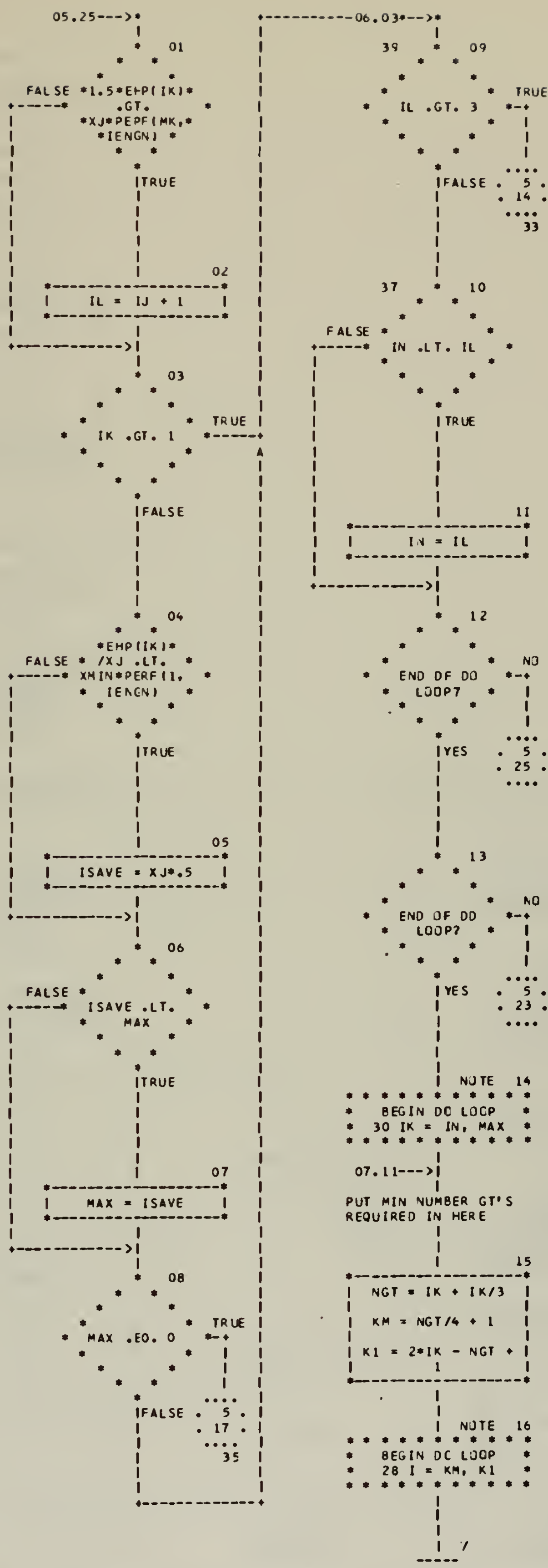

FIGURE 19 SUBROUTINE H2OJT FLOW DIAGRAM (CONT.)

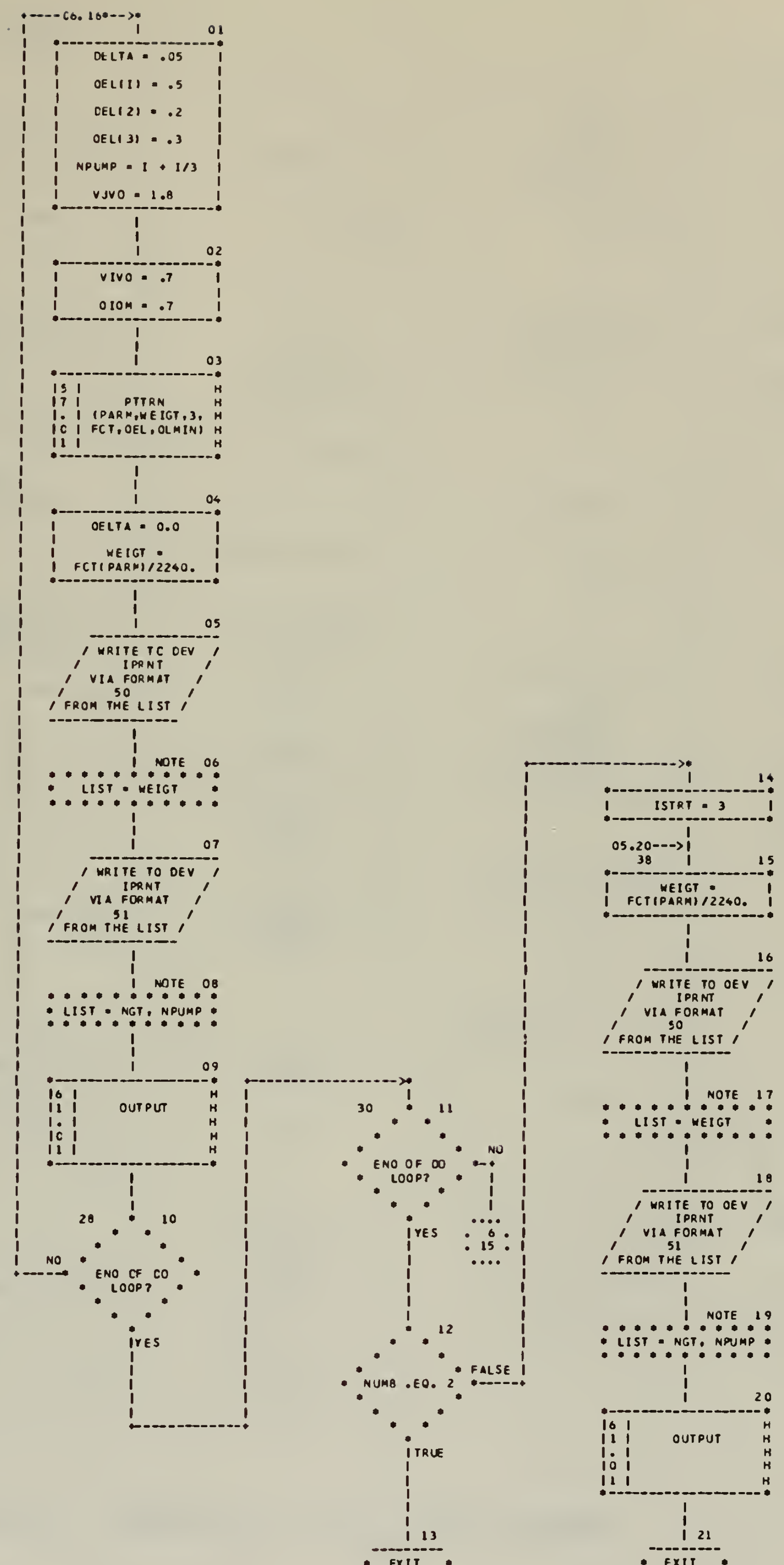

FIGURE 19 SUBROUTINE H2OJT FLOW DIAGRAM (CONT.)

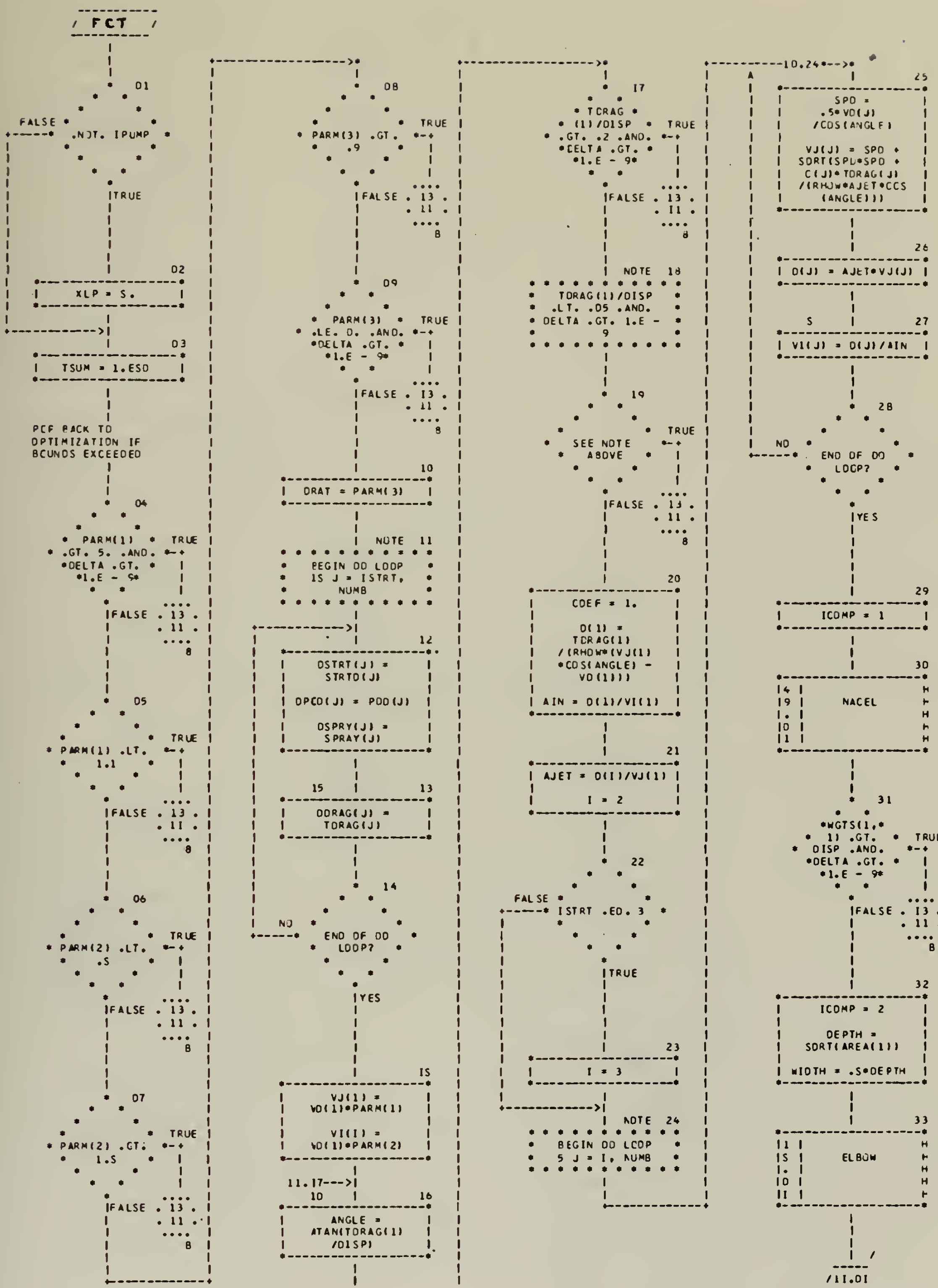

FIGURE 20 SUBROUTINE FCT FLOW DIAGRAM

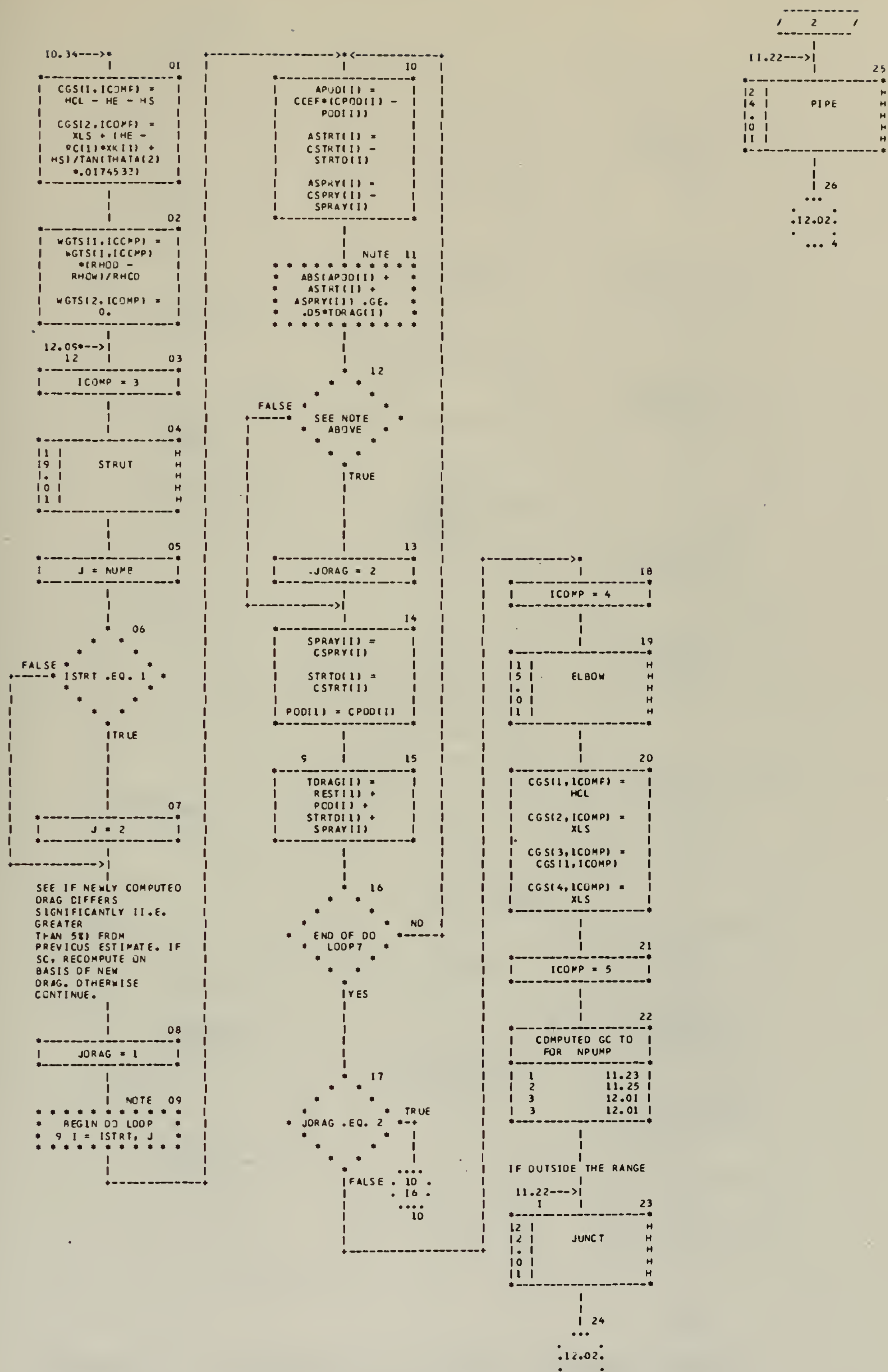

FIGURE 20 SUBROUTINE FCT FLOW DIAGRAM (CONT.)

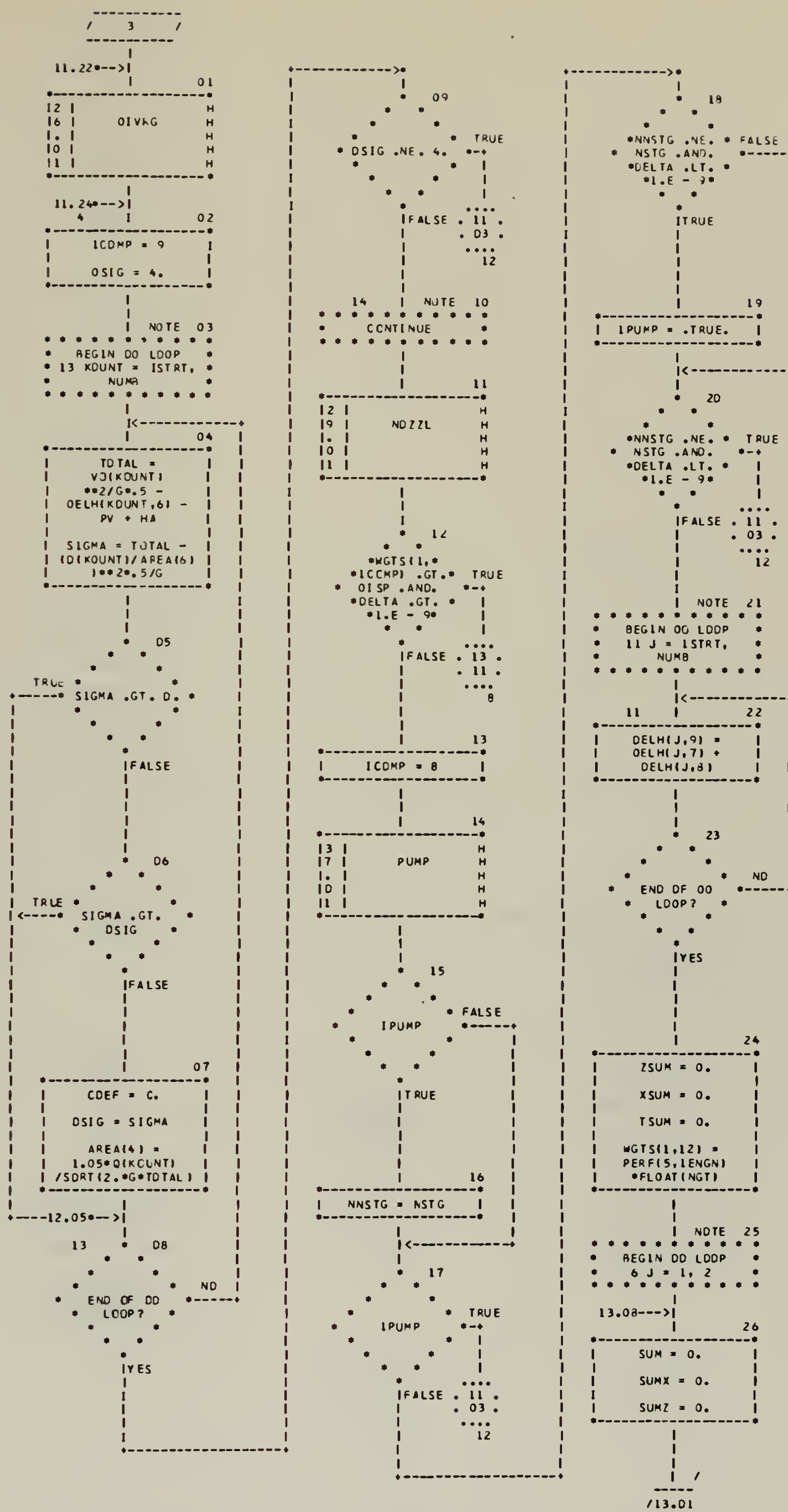

FIGURE 20 SUBROUTINE FCT FLOW DIAGRAM (CONT.)

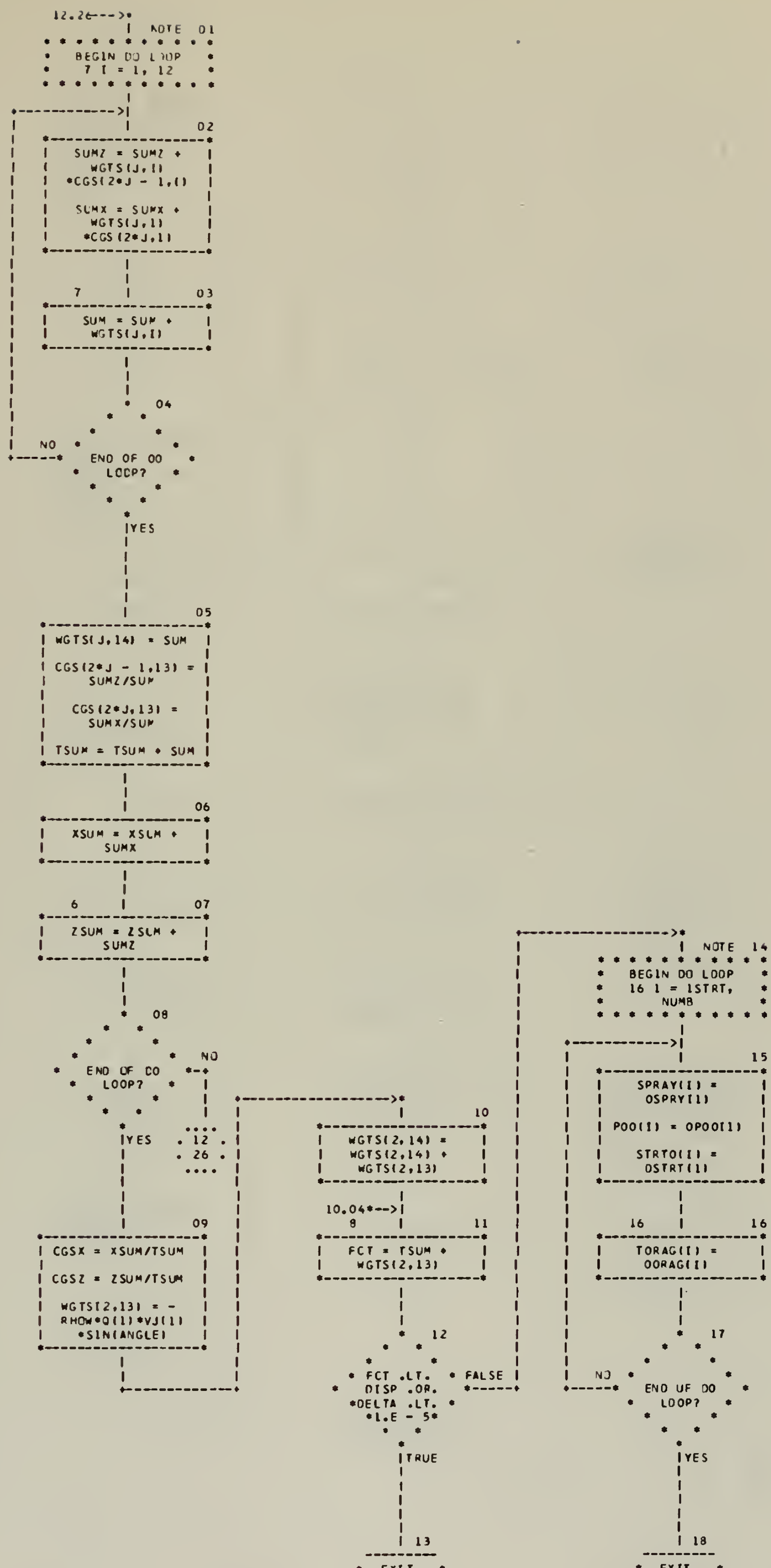

FIGURE 20 SUBROUTINE FCT FLOW DIAGRAM (CONT.)

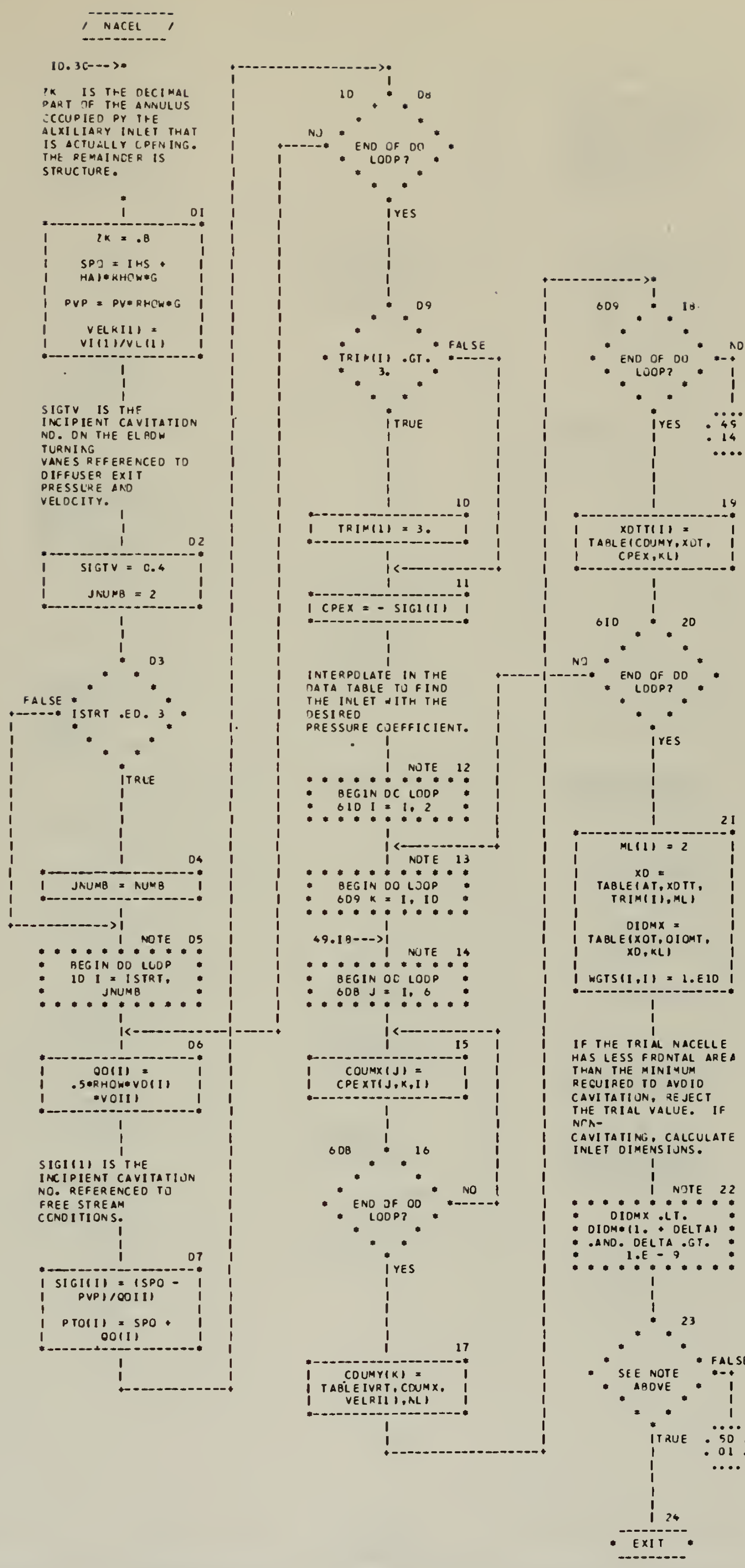

FIGURE 21 SUBROUTINE NACEL FLOW DIAGRAM

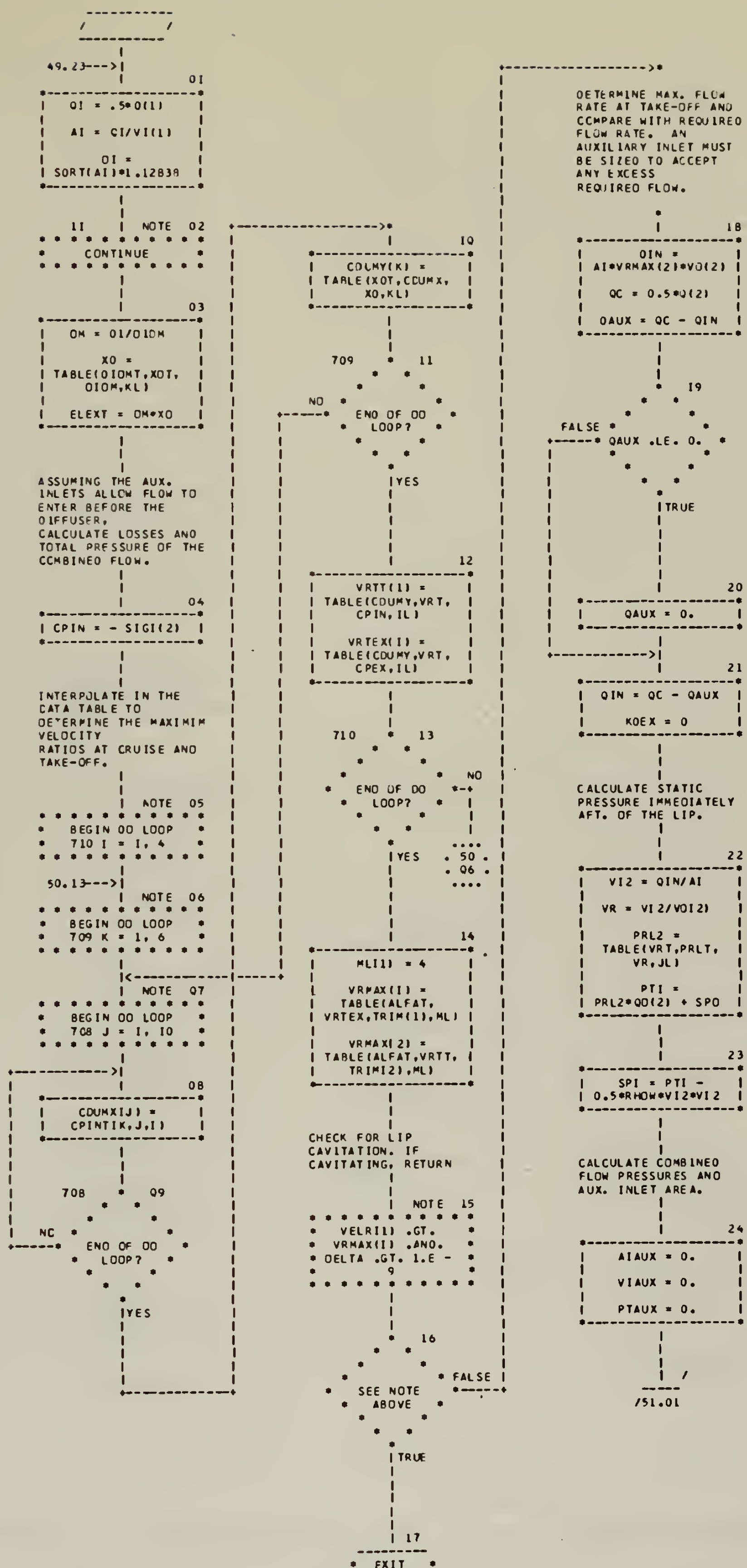

FIGURE 21 SUBROUTINE NACEL FLOW DIAGRAM (CONT.)

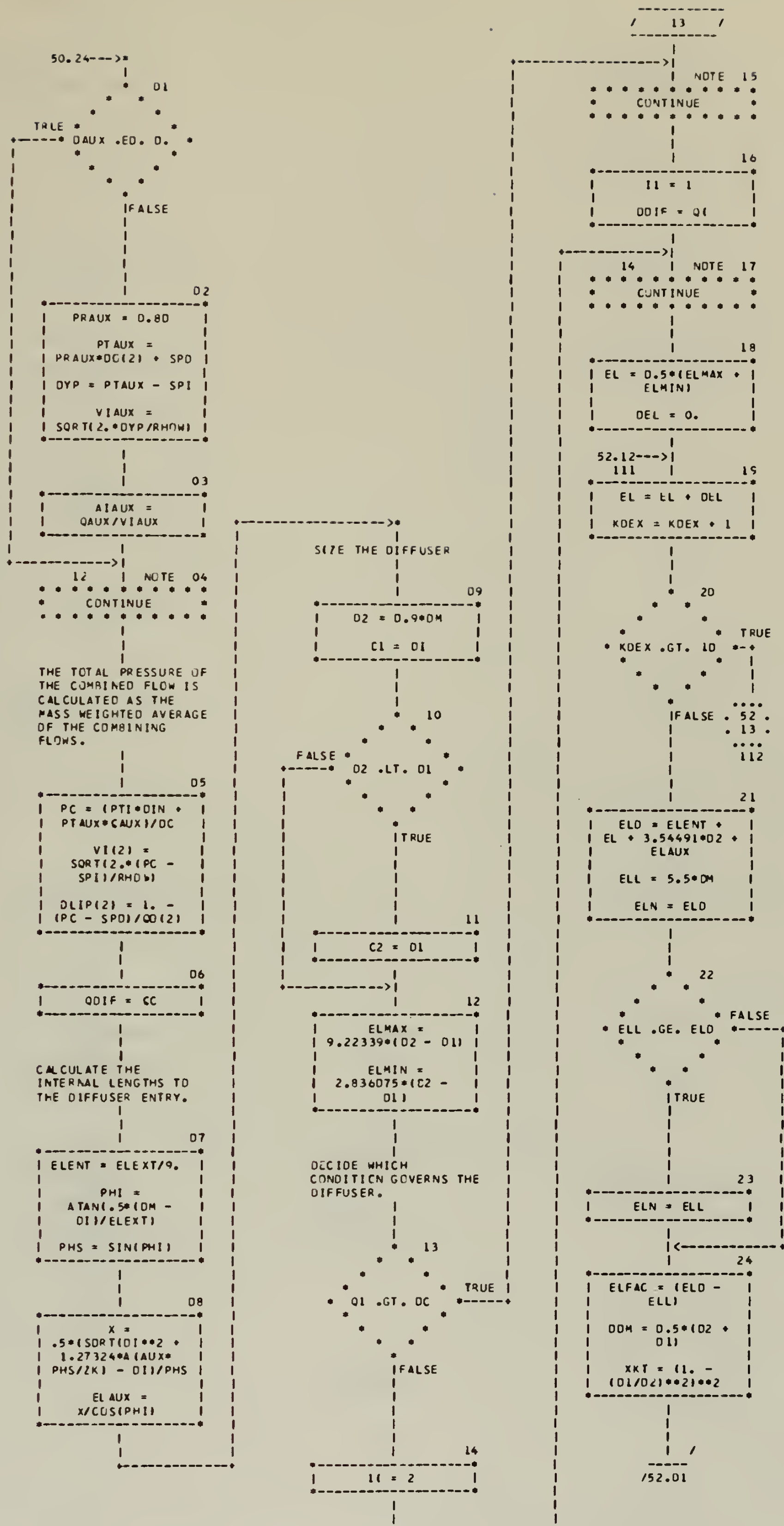

FIGURE 21 SUBROUTINE NACEL FLOW DIAGRAM (CONT.)

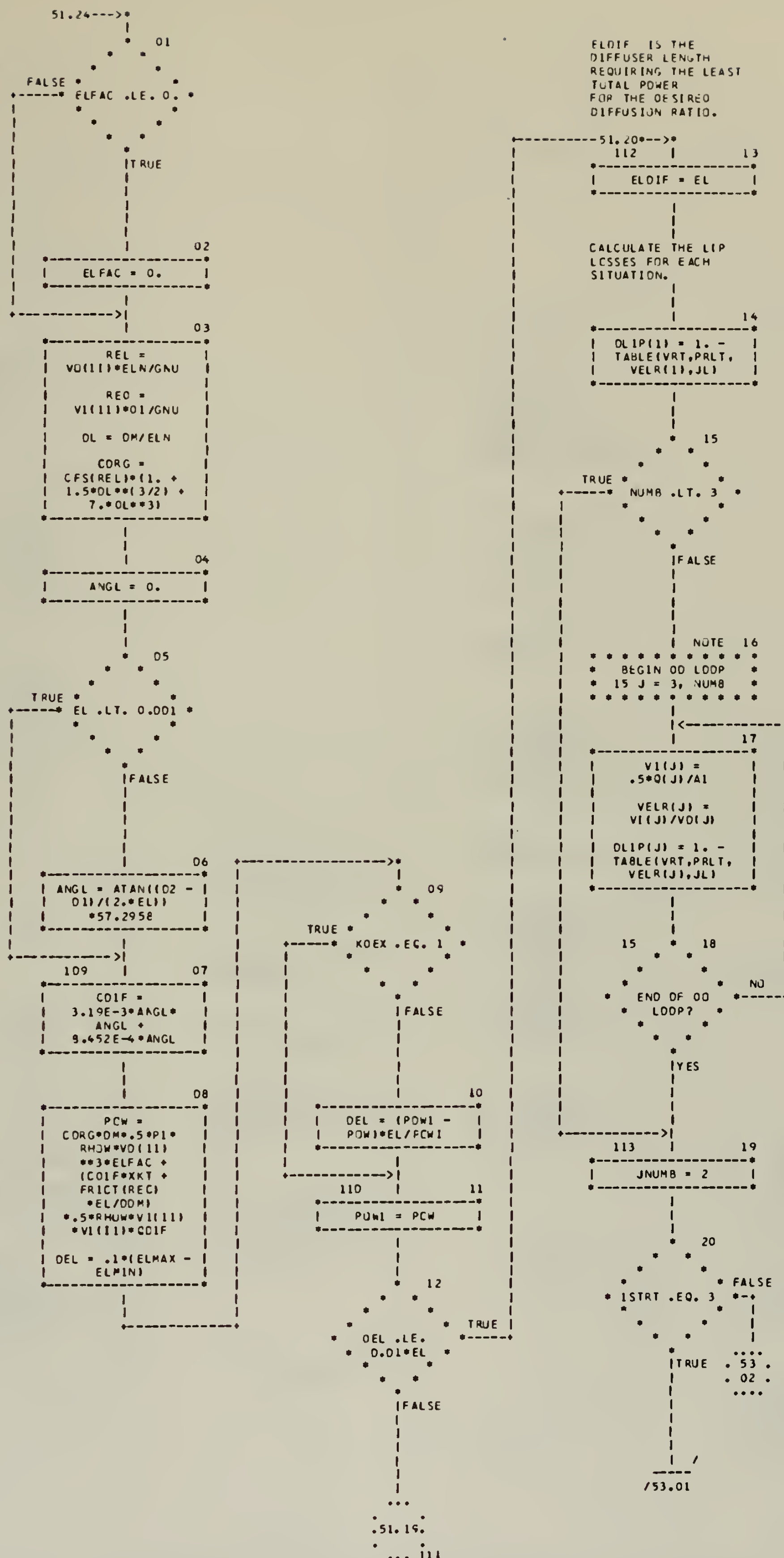

FIGURE 21 SUBROUTINE NACEL FLOW DIAGRAM (CONT.)

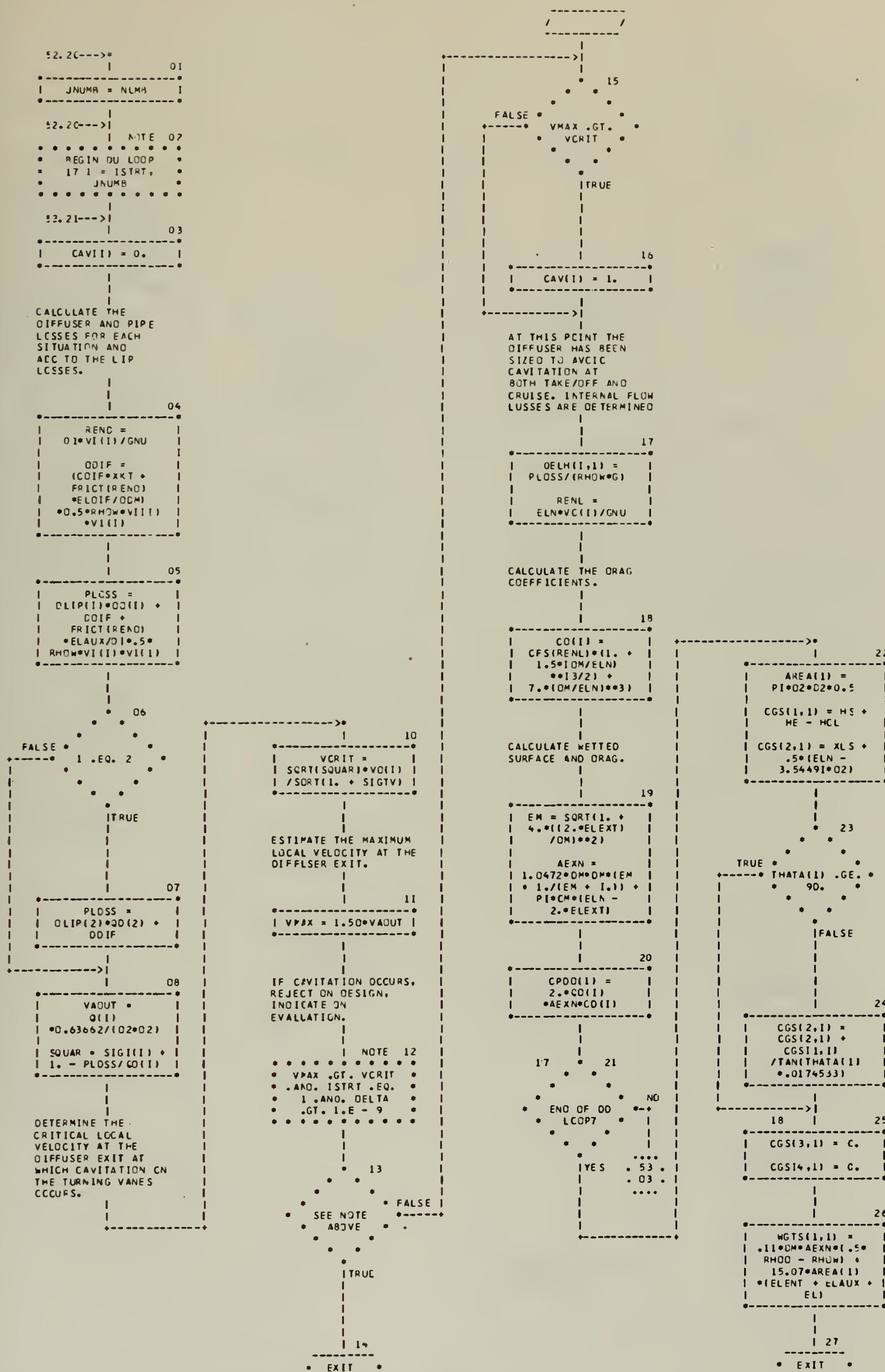

FIGURE 21 SUBROUTINE NACEL FLOW DIAGRAM (CONT.)

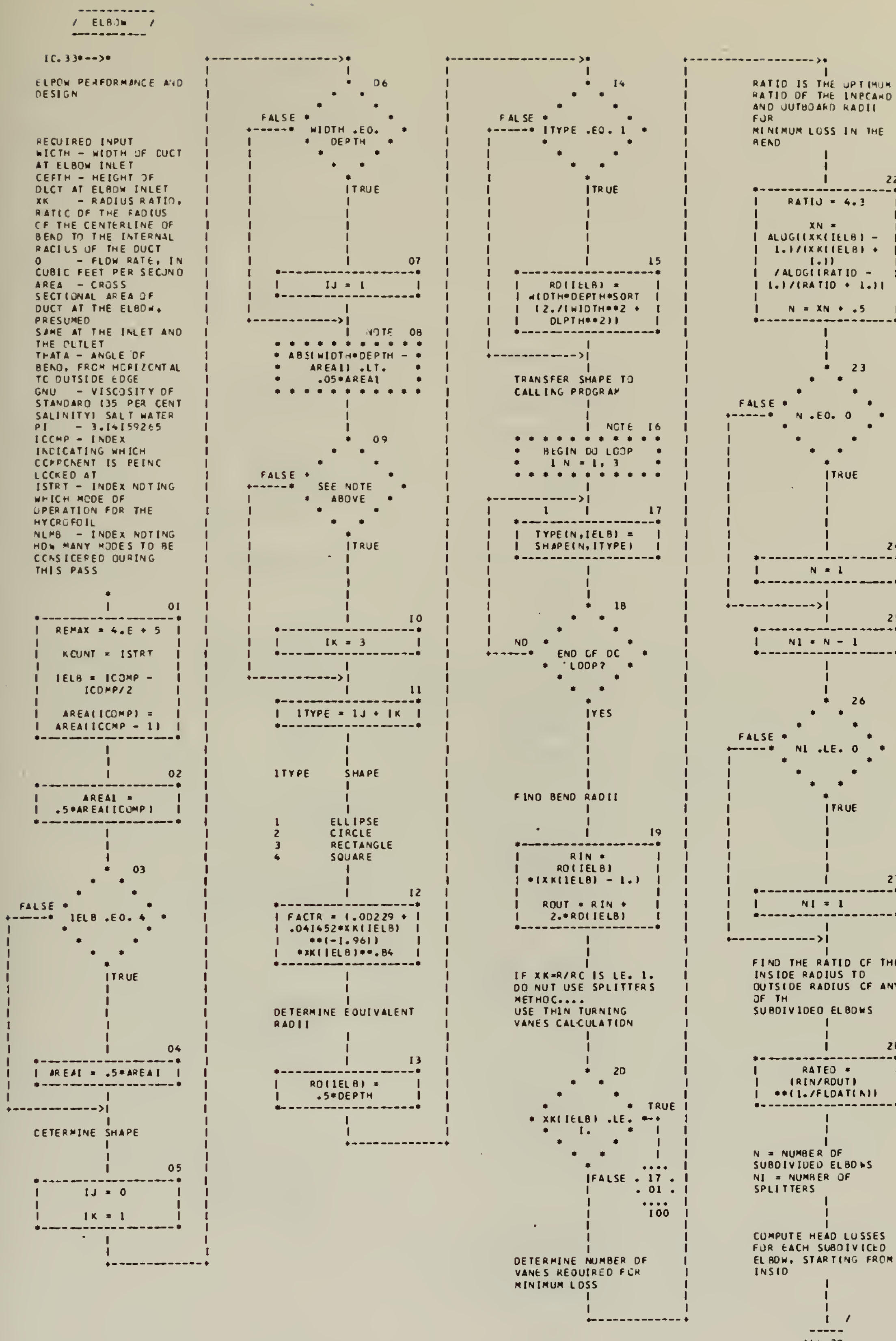

FIGURE 22 SUBROUTINE ELBOW FLOW DIAGRAM

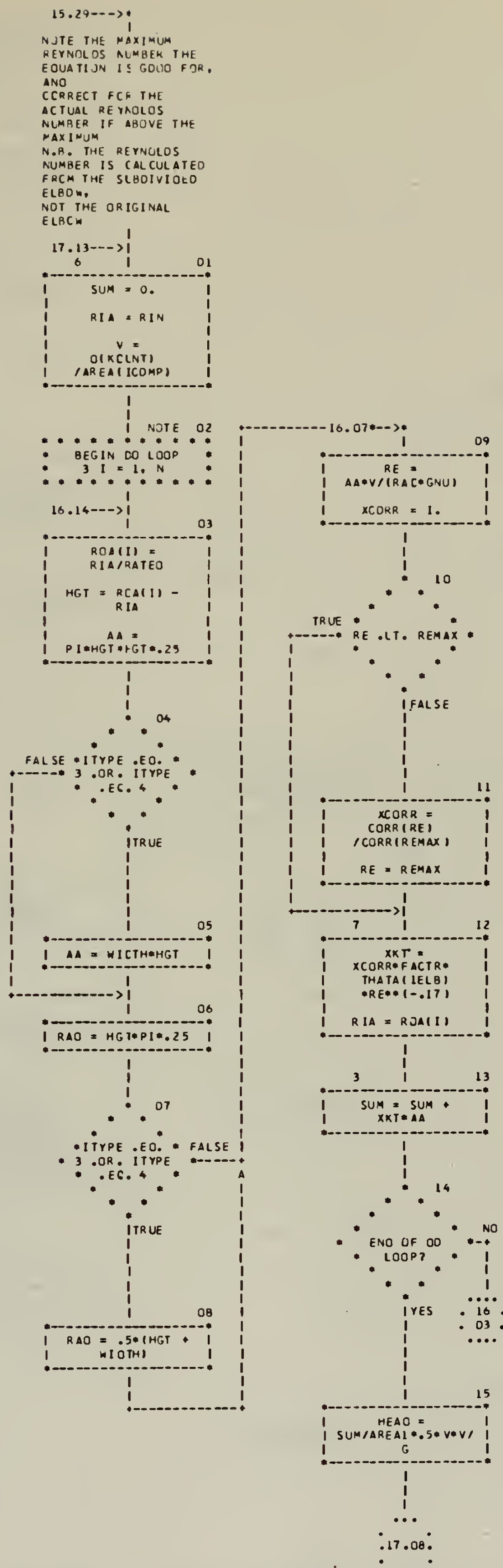

FIGURE 22 SUBROUTINE ELBOW FLOW DIAGRAM (CONT.)

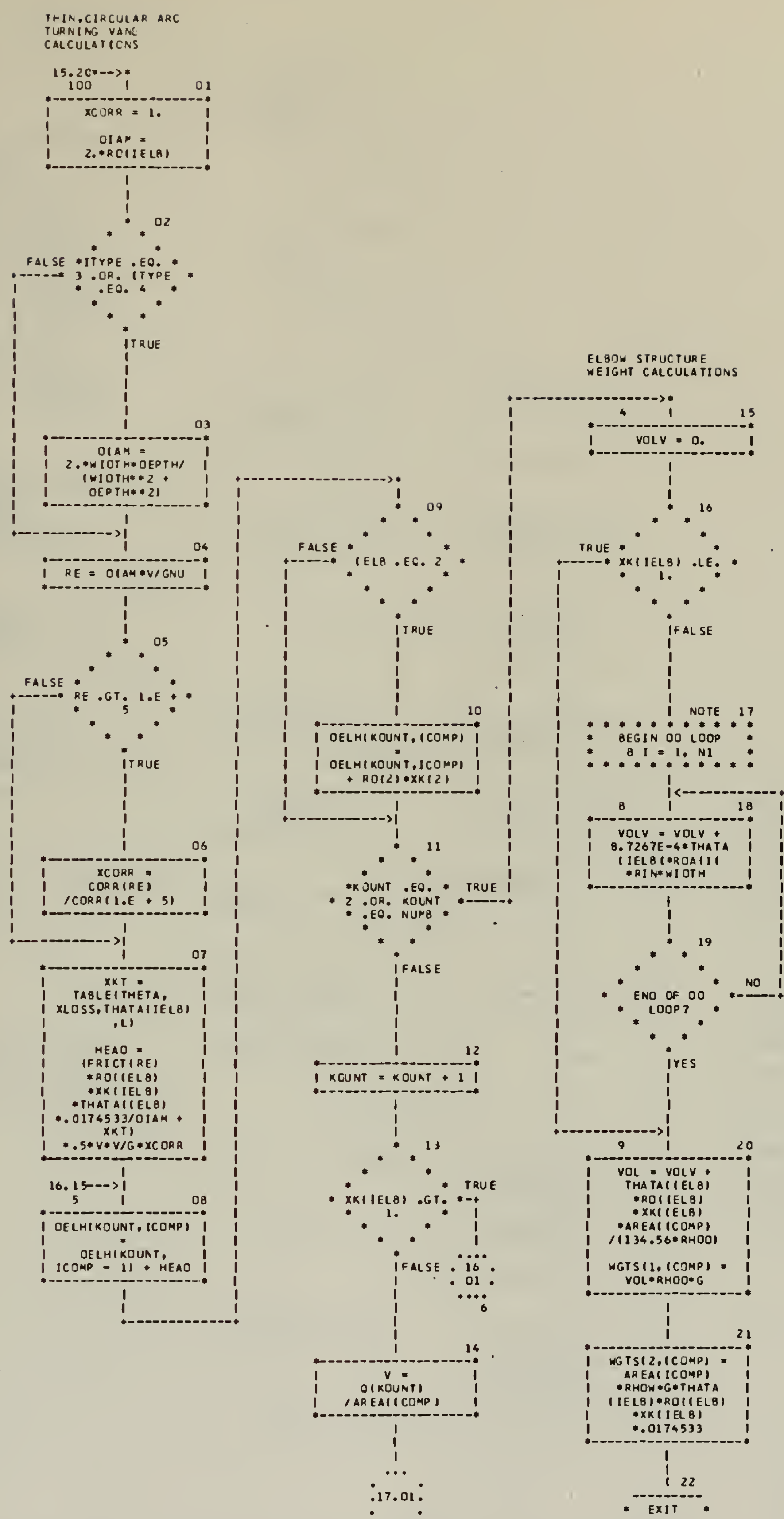

FIGURE 22 SUBROUTINE ELBOW FLOW DIAGRAM (CONT.)

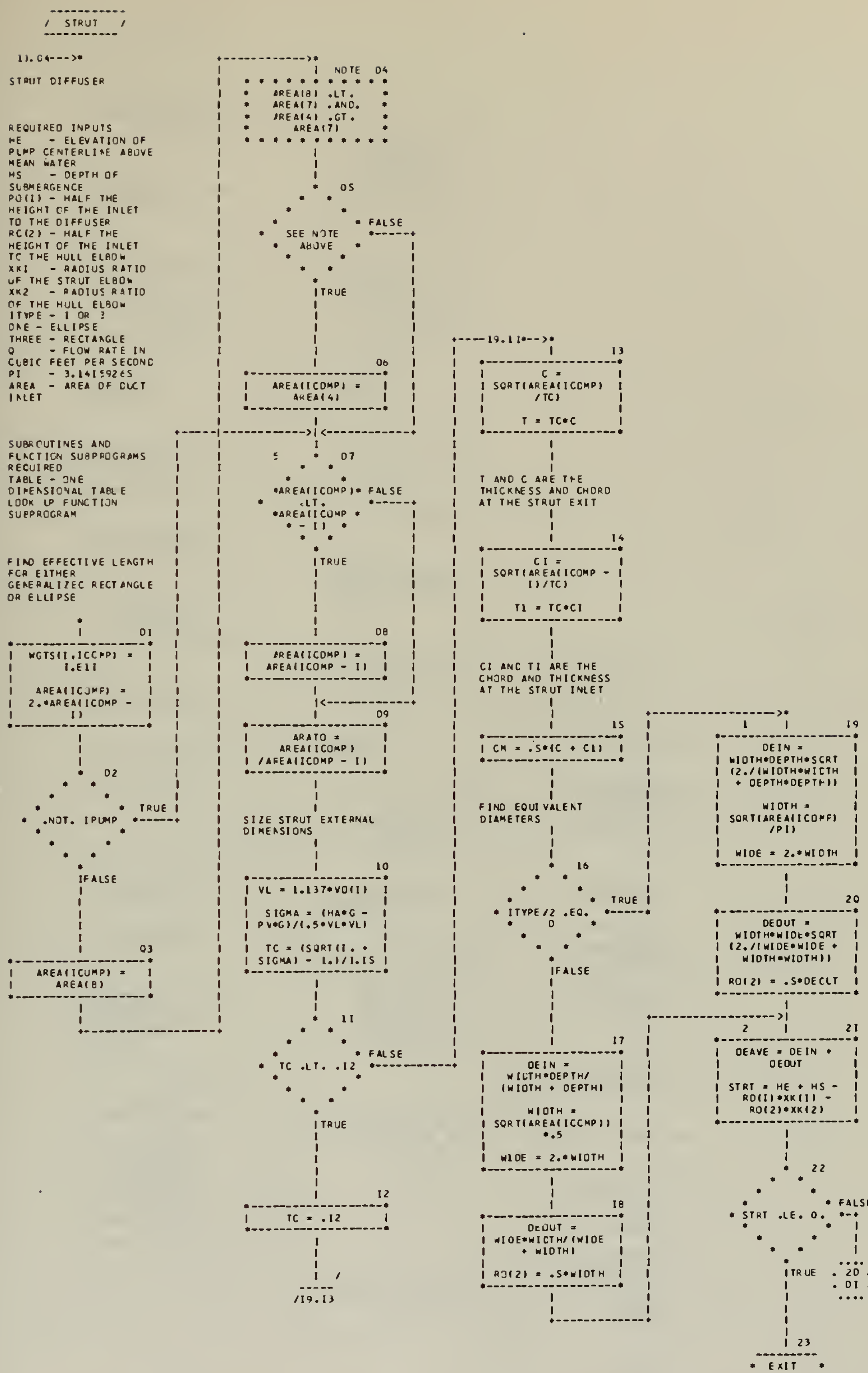

FIGURE 23 SUBROUTINE STRUT FLOW DIAGRAM

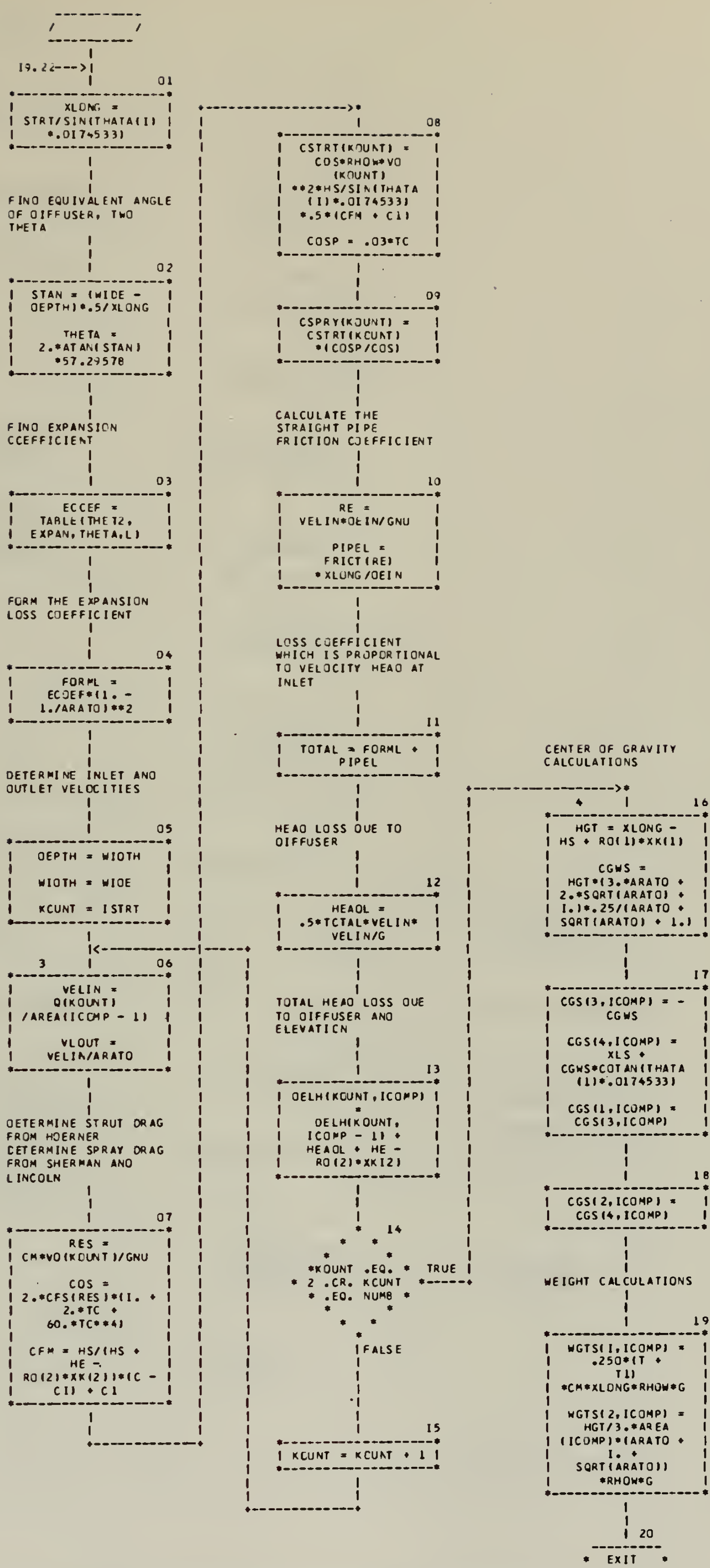

FIGURE 23 SUBROUTINE STRUT FLOW DIAGRAM (CONT.)

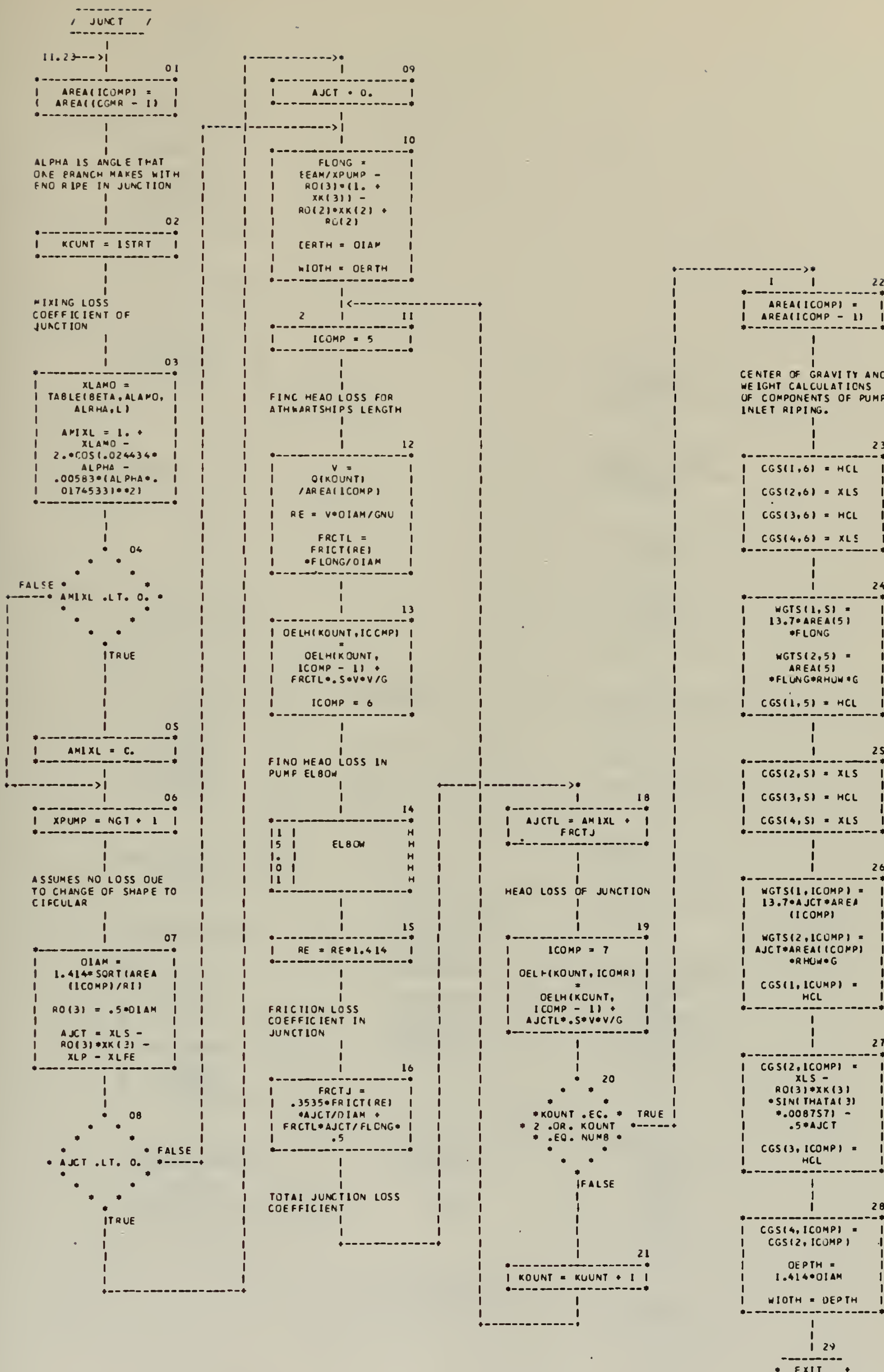

FIGURE 24 SUBROUTINE JUNCT FLOW DIAGRAM

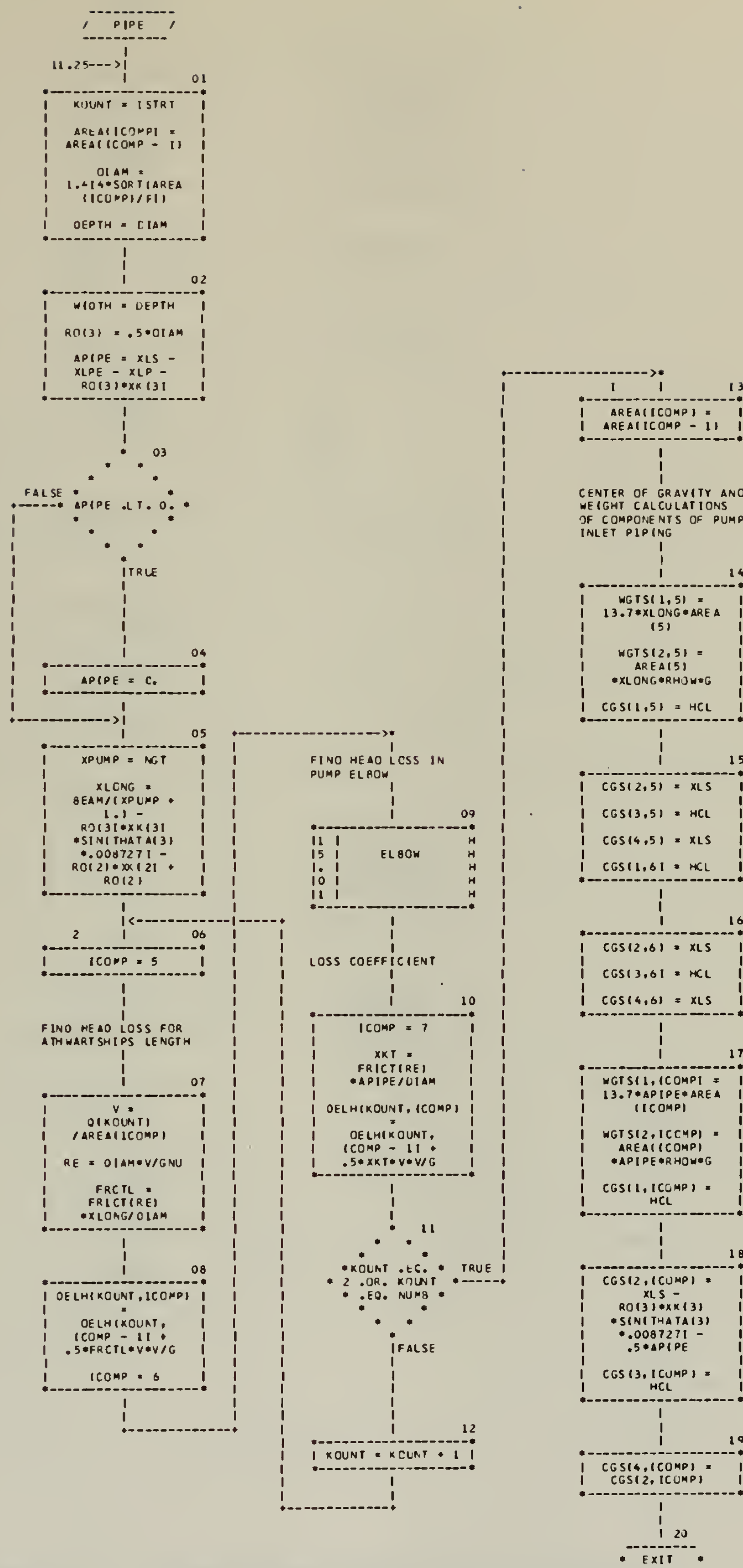

FIGURE 25 SUBROUTINE PIPE FLOW DIAGRAM

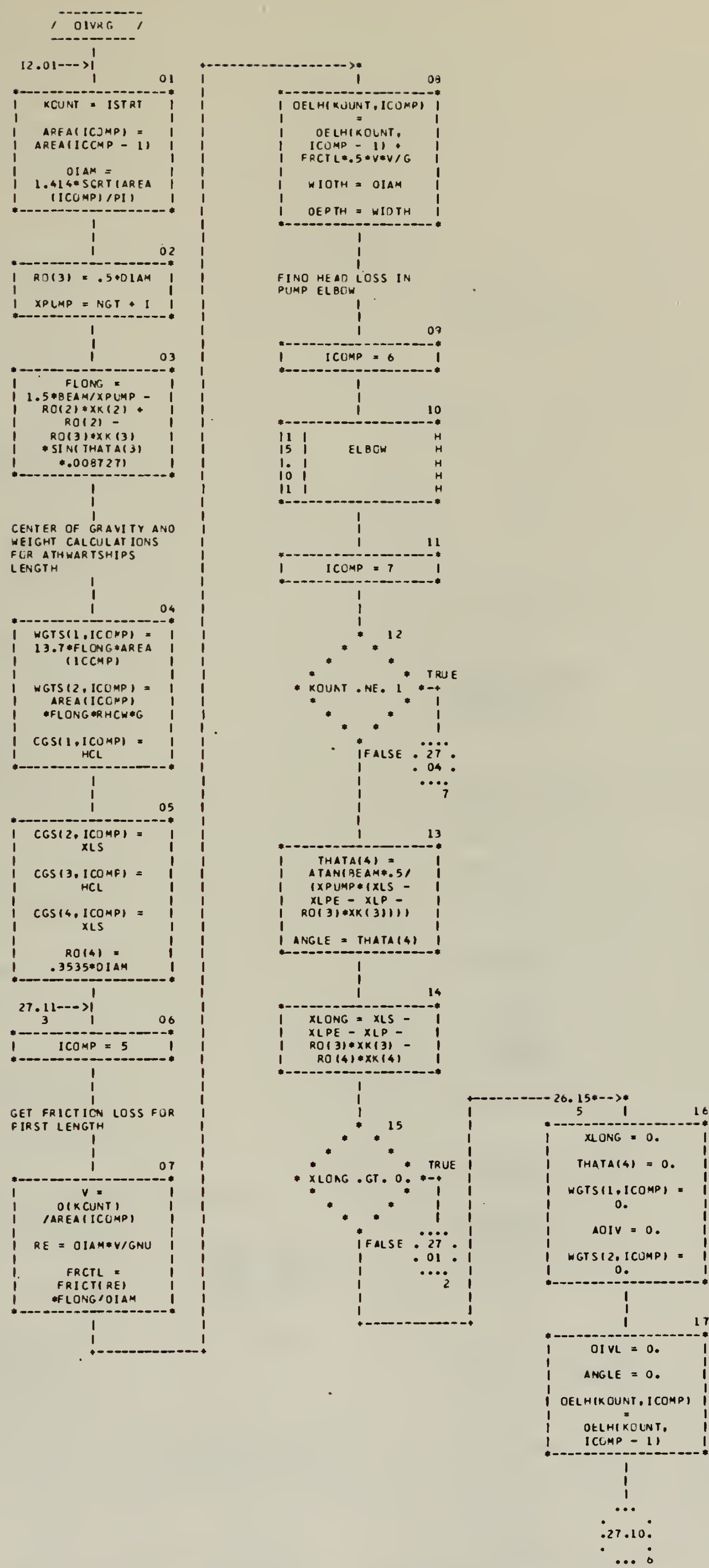

FIGURE 26 SUBROUTINE DIVRG FLOW DIAGRAM

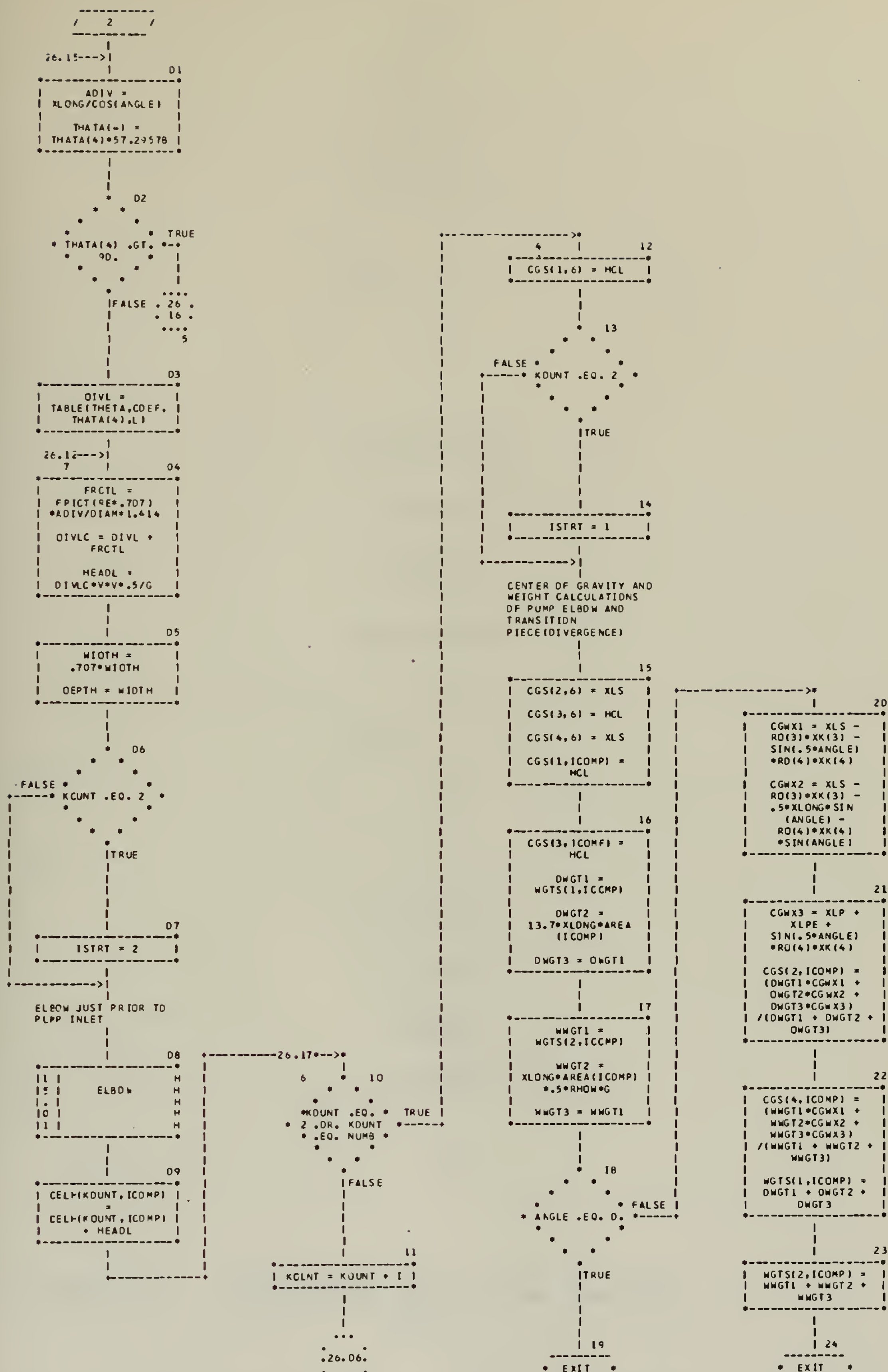

FIGURE 26 SUBROUTINE DIVRG FLOW DIAGRAM (CONT.)

```
                 -----------
                 / NOZZL   /
                 -----------
                      |
          12.11--->|
                      |            01
         *-------------------------*
         |   KOUNT = ISTRT         |
         |                         |
         |   XLPS = XLPE           |
         |                         |
         |   XFAC =                |
         |   1.4*HCL/XLPE          |
         |                         |
         |   XPUMP = NPUMP         |
         *-------------------------*
                      |
                      |
                      |
                      *    02
                   *     *
                *           *
      FALSE *                 *
    +-----*   .NOT. IPUMP       *
    |       *                 *
    |         *             *
    |            *       *
    |               *
    |               |TRUE
    |               |
    |               |
    |               |
    |               |              03
    |    *-------------------------*
    |    | AREA(8) = AREA(7)       |
    |    *-------------------------*
    |               |
    +------------>|
                    |              04
         *-------------------------*
         |   AREA(ICOMP) =         |
         |   AJET                  |
         |                         |
         |   ANOZ =                |
         |   ATAN(TORAG(1)         |
         |   /CISP)                |
         *-------------------------*
                      |
                      |
                      |
         XFAC.LT.1. INDICATES
         NOZZLE EXITS THROUGH
         BOTTOM
                      |
                      |
                      |
                      *    05
                   *     *
                *           *
      FALSE *                 *
    +-----*   XFAC .LT. 1.      *
    |       *                 *
    |         *             *
    |            *       *
    |               *
    |               |TRUE
    |               |
    |               |
    |               |
    |               |              06
    |    *-------------------------*
    |    | XLPS = 1.4*HCL          |
    |    *-------------------------*
    |               |
    +------------>|
                    |              07
         *-------------------------*
         |   XLNOZ =               |
         |   XLPS/COS(ANOZ)        |
         |                         |
         |   DT =                  |
         |   2.*SQRT(AREA          |
         |   (ICOMP -              |
         |   1)/(PI*XPUMP))        |
         |                         |
         |   DJ =                  |
         |   2.*SQRT(AJET/(PI*     |
         |   XPUMP))               |
         *-------------------------*
                      |
                      |
                      |  /
                    -----
                   /30.01
```

FIGURE 27 SUBROUTINE NOZZL FLOW DIAGRAM

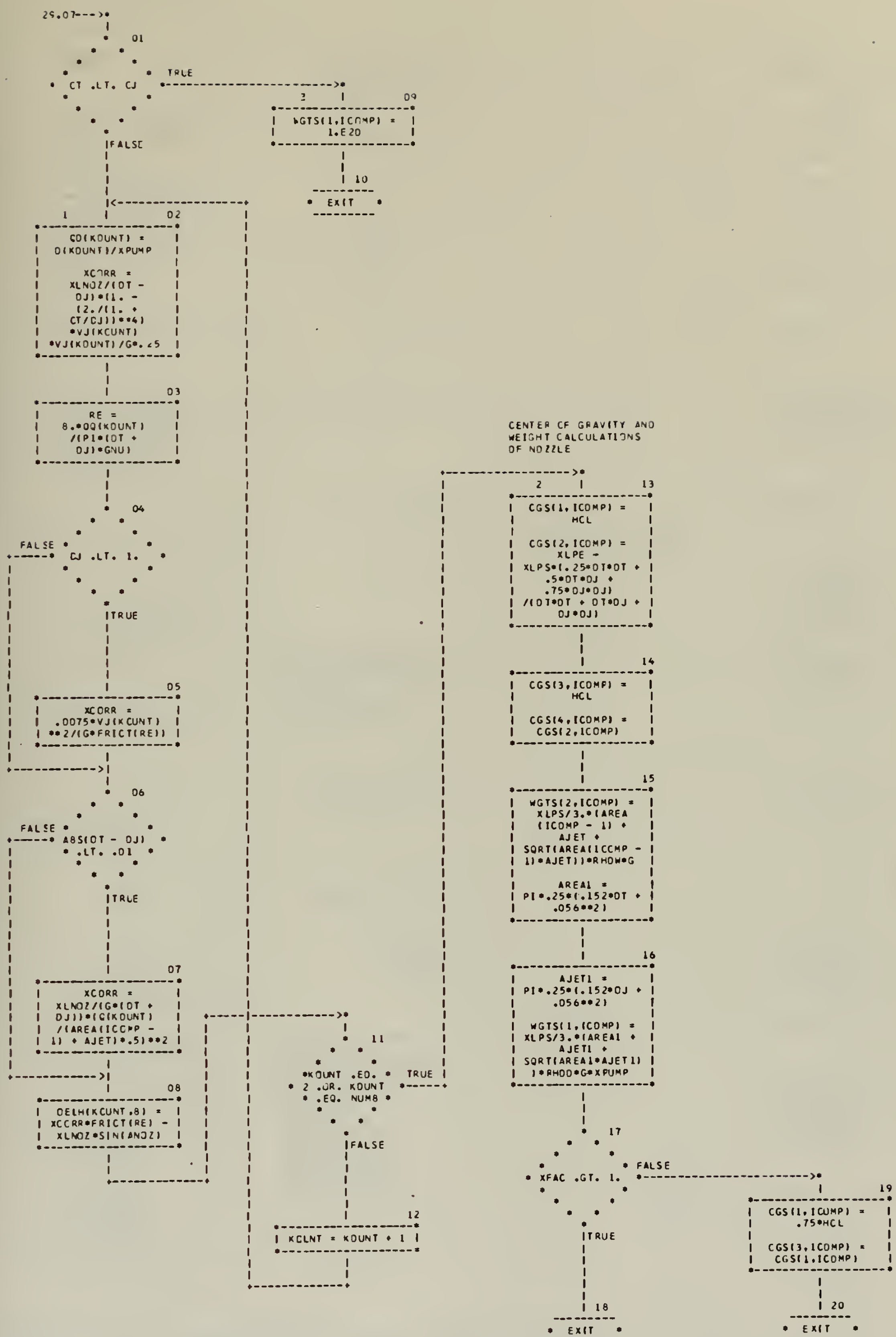

FIGURE 27 SUBROUTINE NOZZL FLOW DIAGRAM (CONT.)

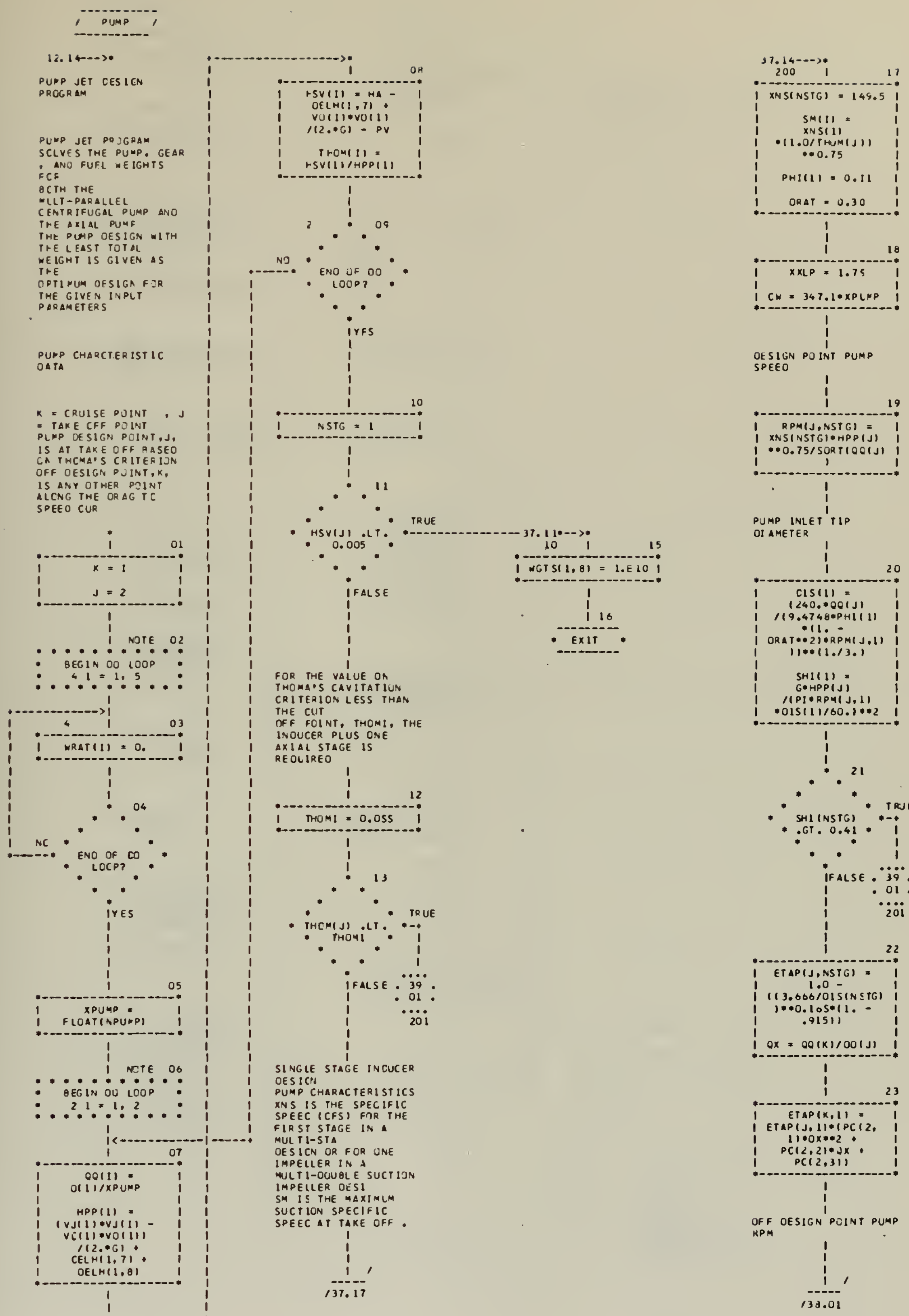

FIGURE 28 SUBROUTINE PUMP FLOW DIAGRAM

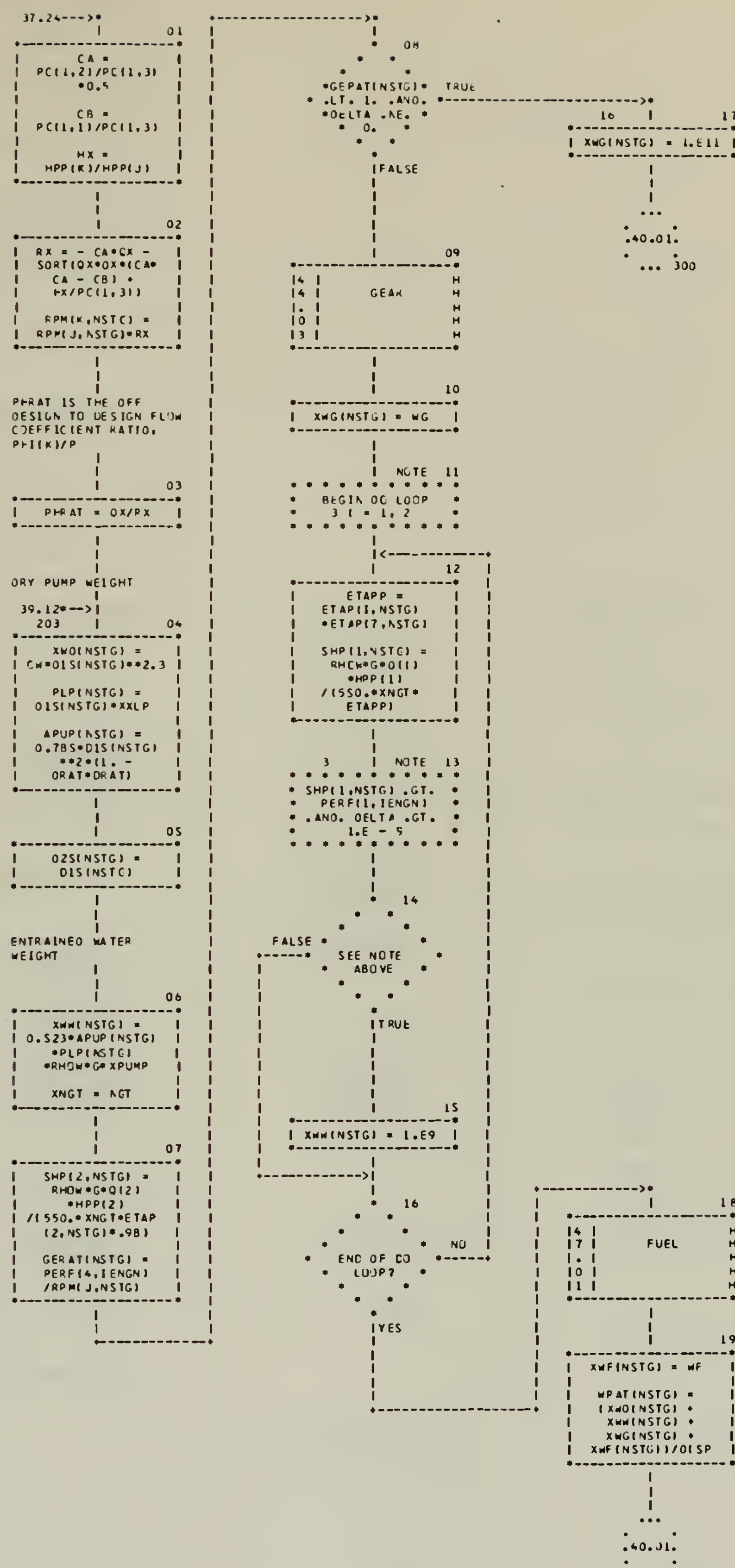

FIGURE 28 SUBROUTINE PUMP FLOW DIAGRAM (CONT.)

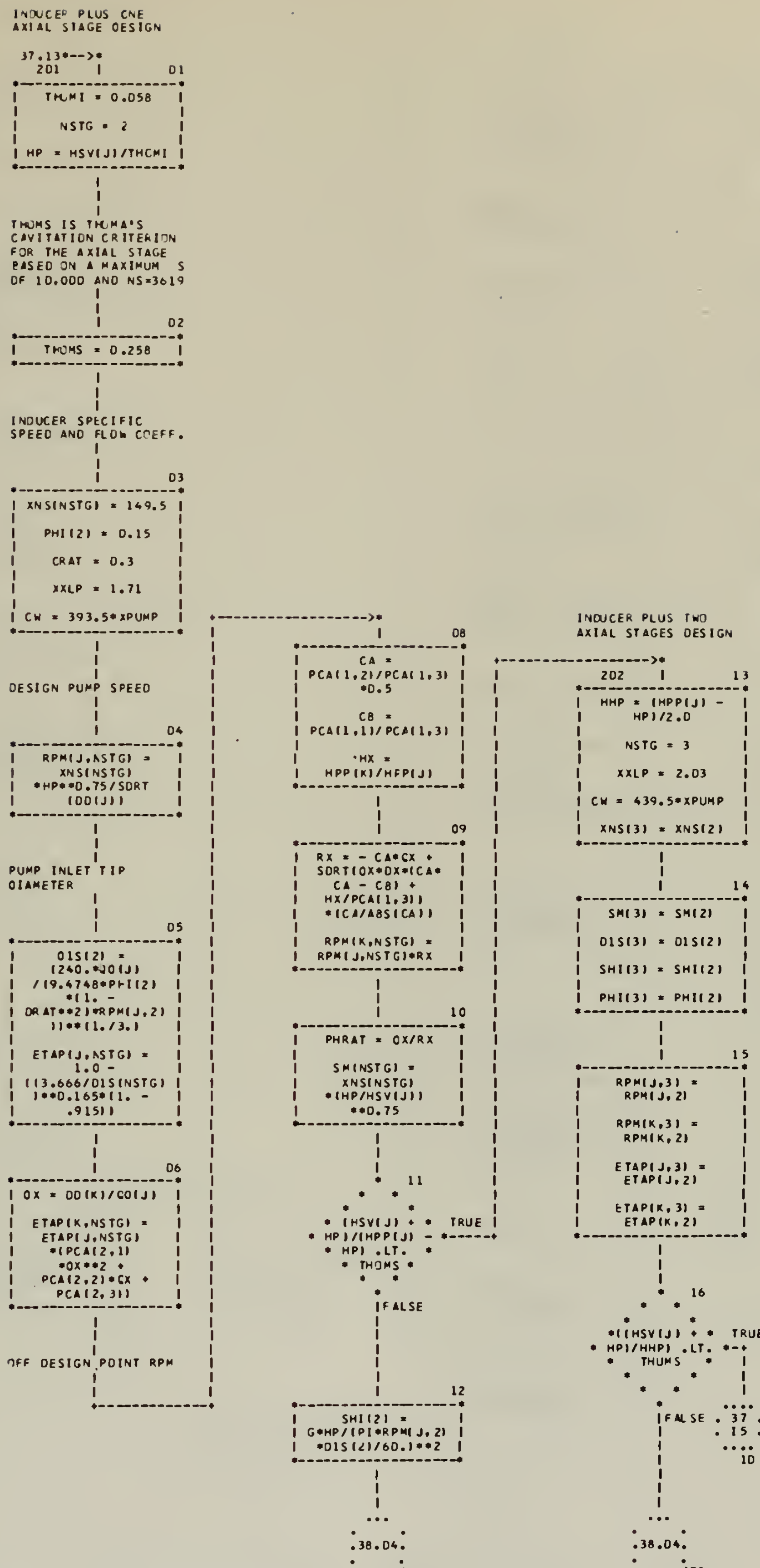

FIGURE 28 SUBROUTINE PUMP FLOW DIAGRAM (CONT.)

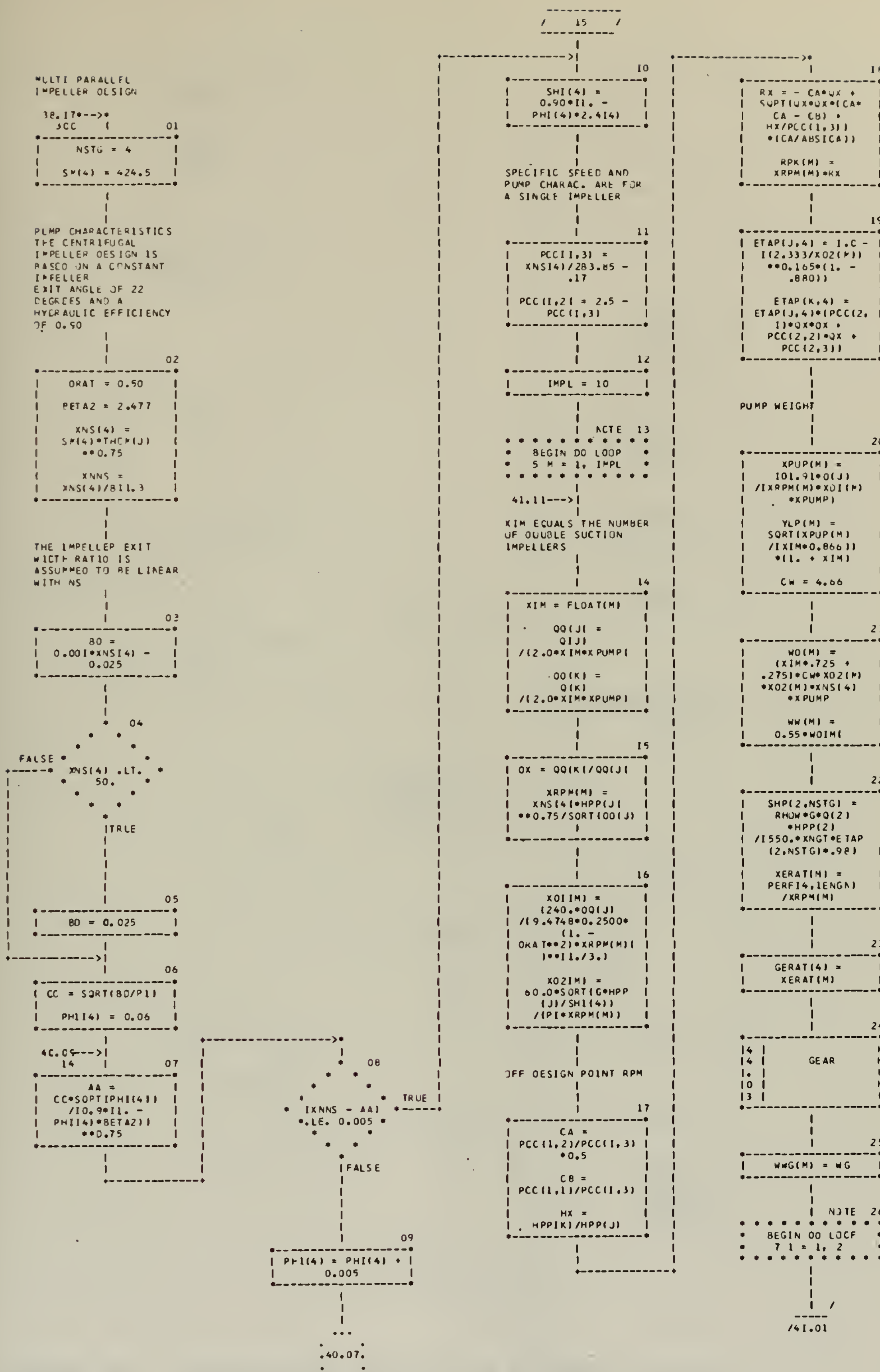

FIGURE 28 SUBROUTINE PUMP FLOW DIAGRAM (CONT.)

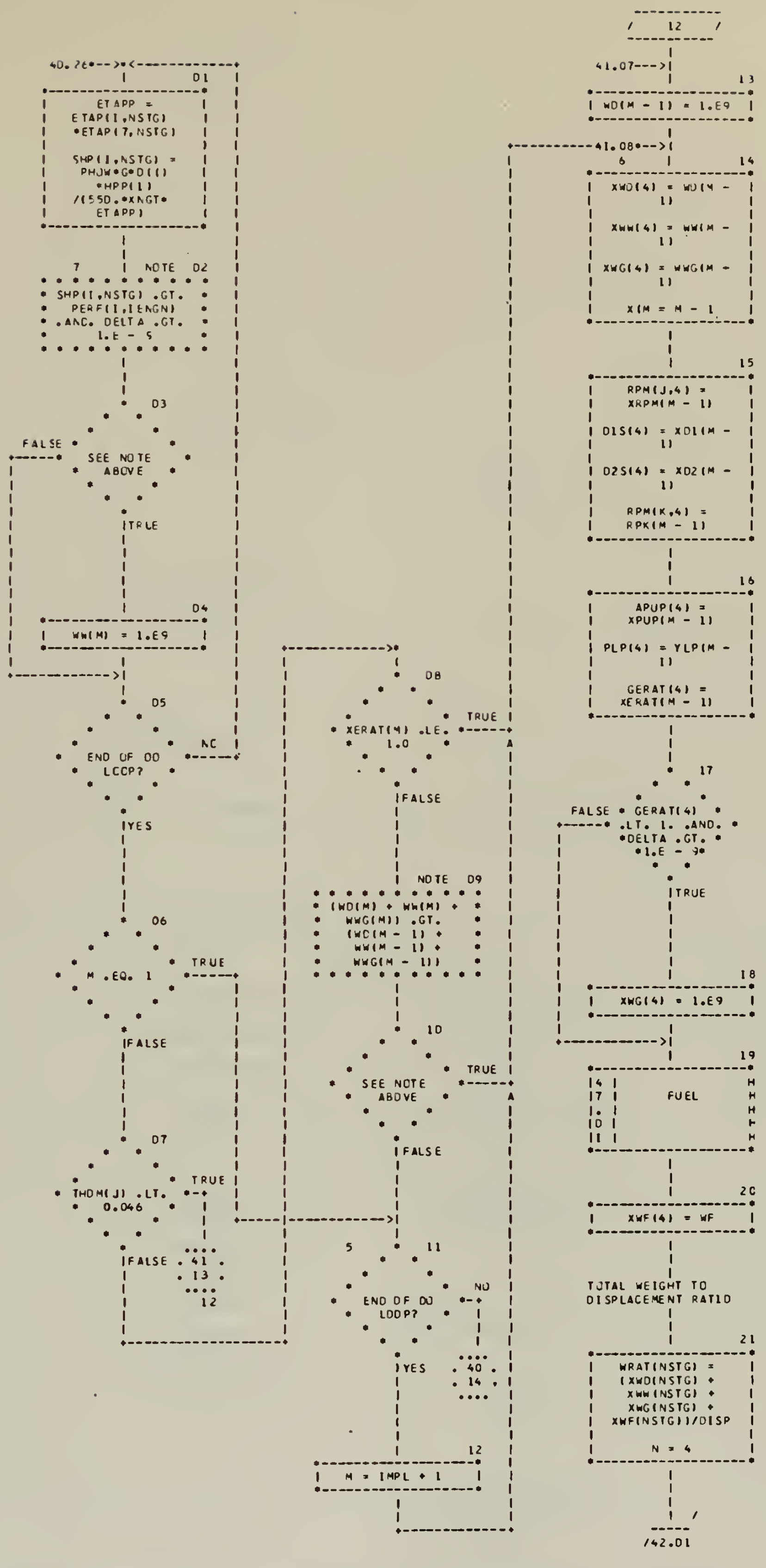

FIGURE 28 SUBROUTINE PUMP FLOW DIAGRAM (CONT.)

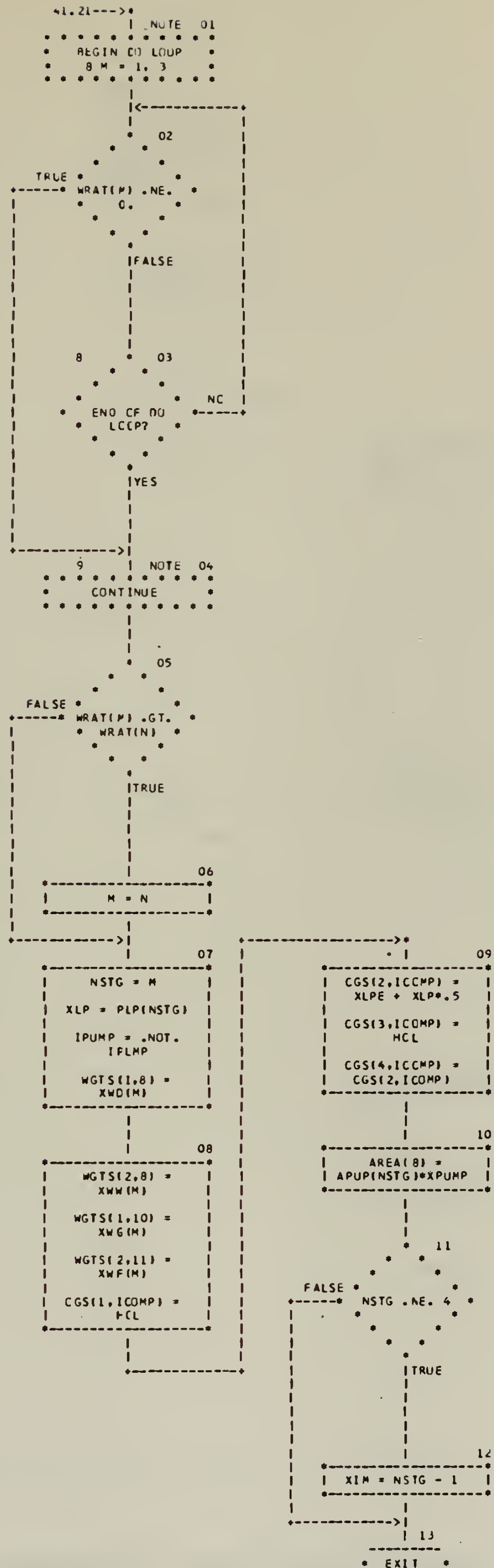

FIGURE 28 SUBROUTINE PUMP FLOW DIAGRAM (CONT.)

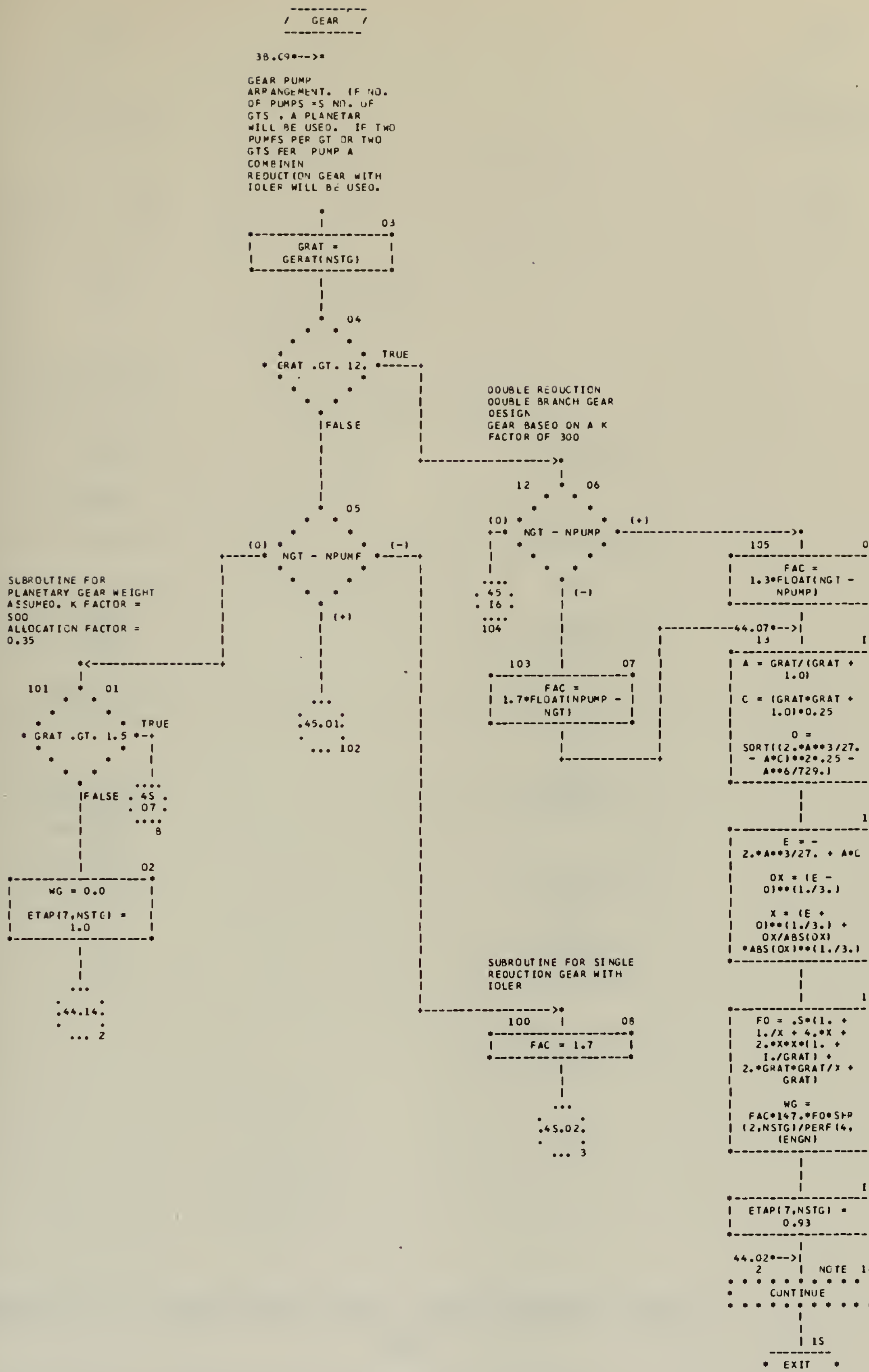

FIGURE 29 SUBROUTINE GEAR FLOW DIAGRAM

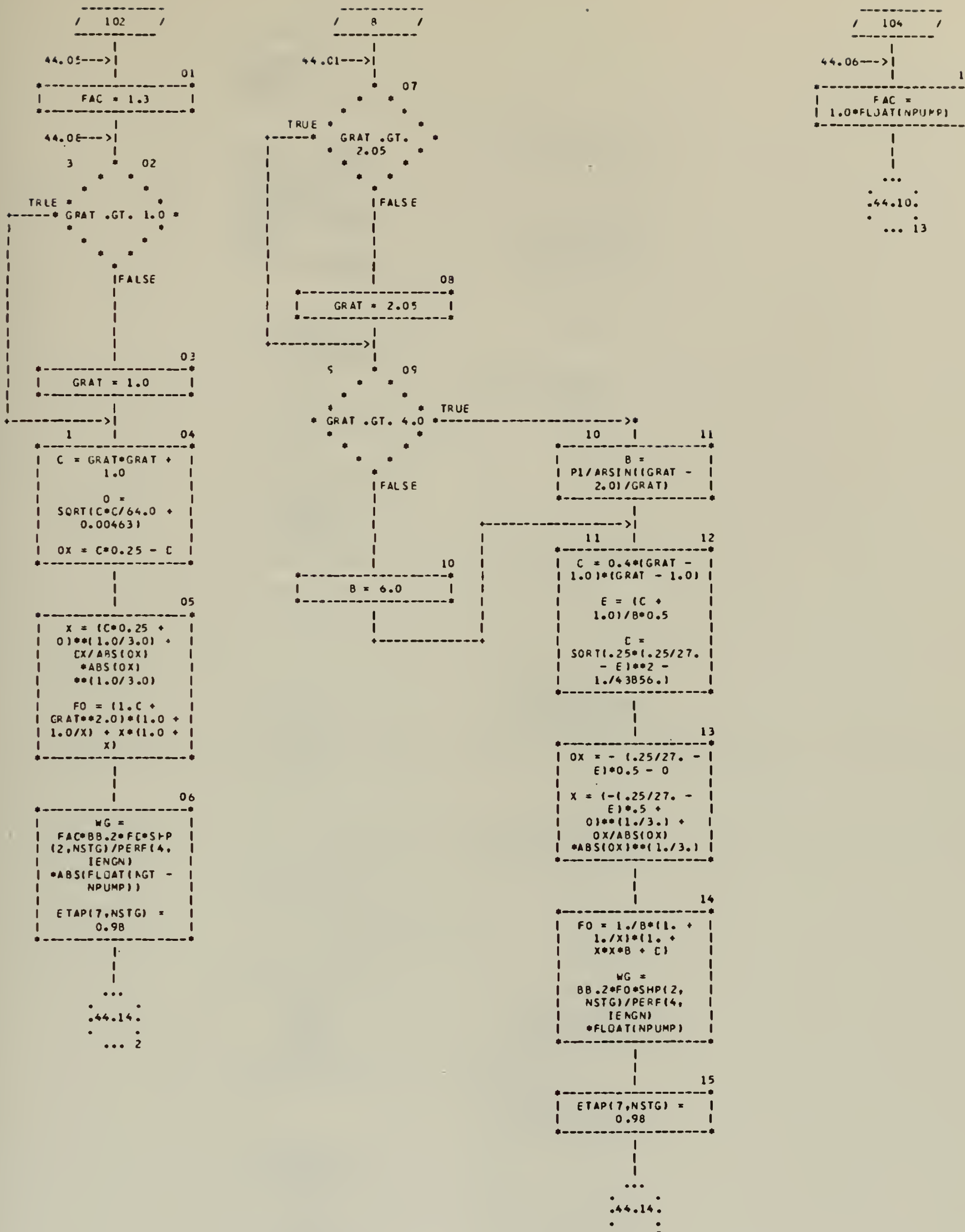

FIGURE 29 SUBROUTINE GEAR FLOW DIAGRAM (CONT.)

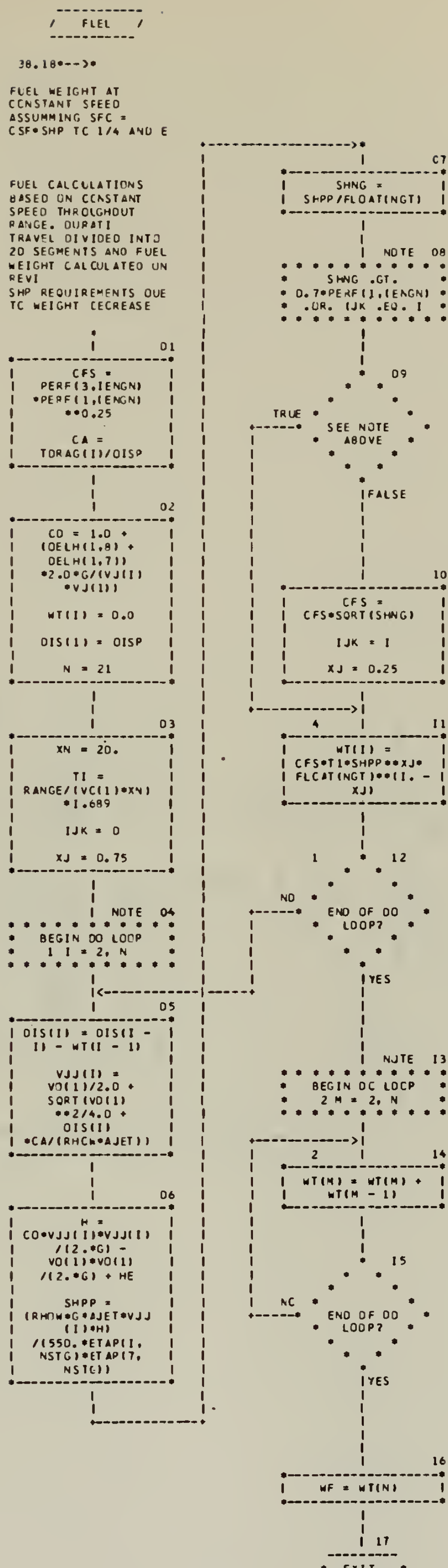

FIGURE 30 SUBROUTINE FUEL FLOW DIAGRAM

```
              SCHOENHERR SKIN
              FRICTION COEFFICIENT

                     *
                     |           01
              *-------------------*
              |   CFS = 0.004     |
              *-------------------*
                     |
        +----------->|
        |       1    |           02
        |     *-------------------*
        |     |      DCFS =       |
        |     | (0.242/ALOG10(R*  |
        |     |  CFS))**2 - CFS   |
        |     |                   |
        |     | CFS = CFS + DCFS  |
        |     *-------------------*
        |            |
        |            |
        |            |
        |            *    03
        |         *     *
        |       *         *
        | TRUE *            *
        +-----*   DCFS .GT.    *
               *  1.E - 6    *
                 *         *
                   *     *
                     *
                     |FALSE
                     |
                     |
                     |
                     |
                     |
                     | 04
                 ---------
                 *  EXIT   *
                 ---------
```

FIGURE 31 . SUBROUTINE CFS FLOW DIAGRAM

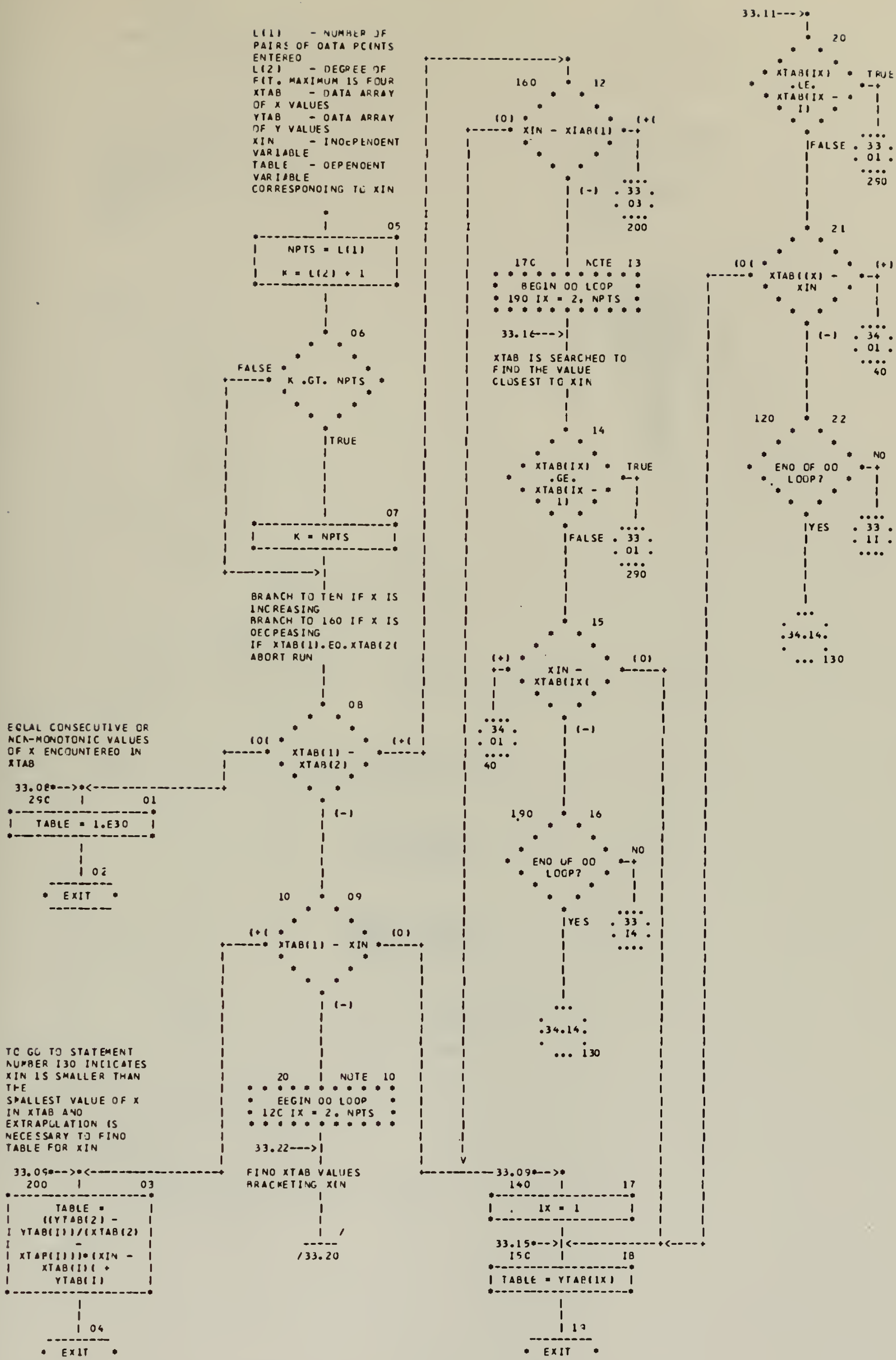

FIGURE 32 SUBROUTINE TABLE FLOW DIAGRAM

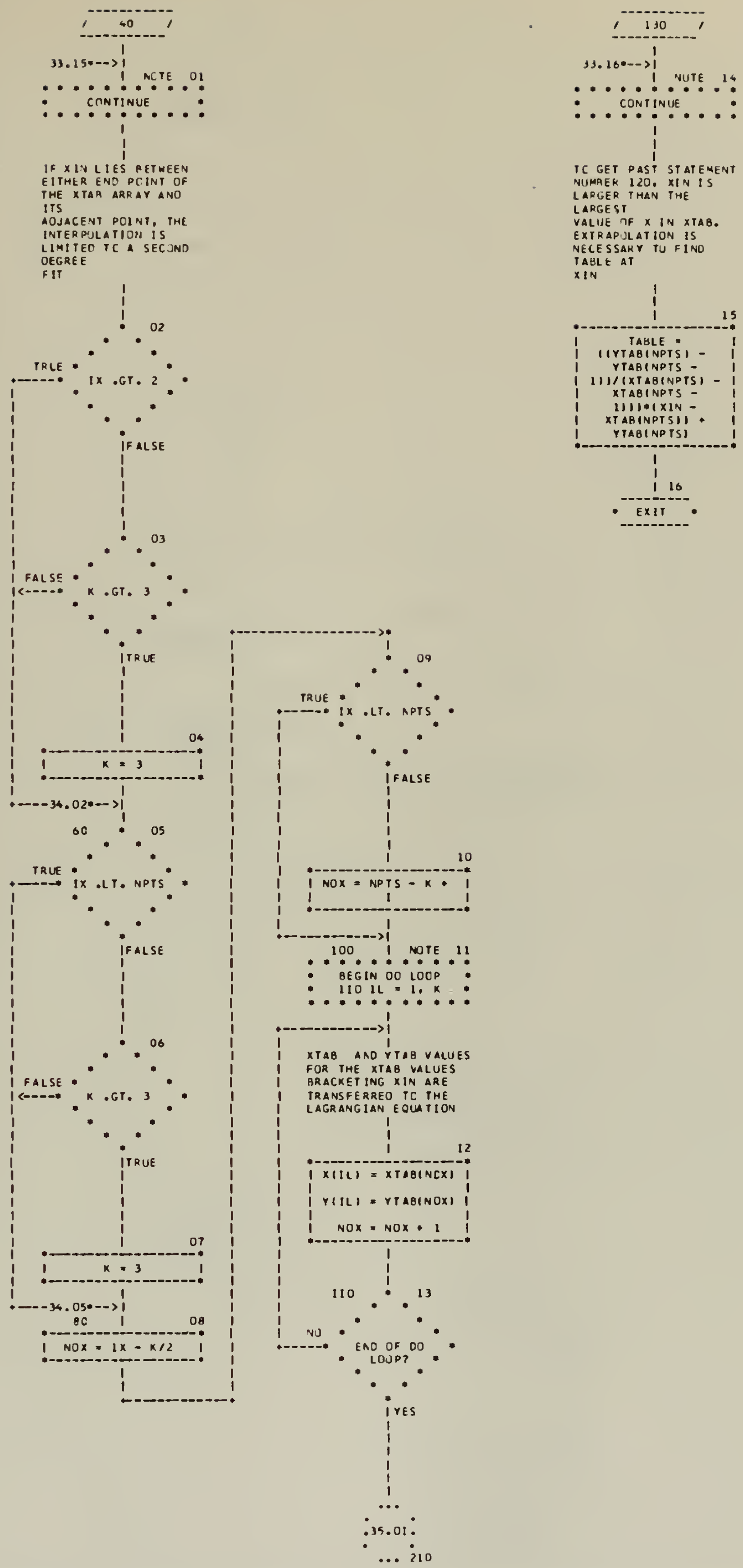

FIGURE 32 SUBROUTINE TABLE FLOW DIAGRAM (CONT.)

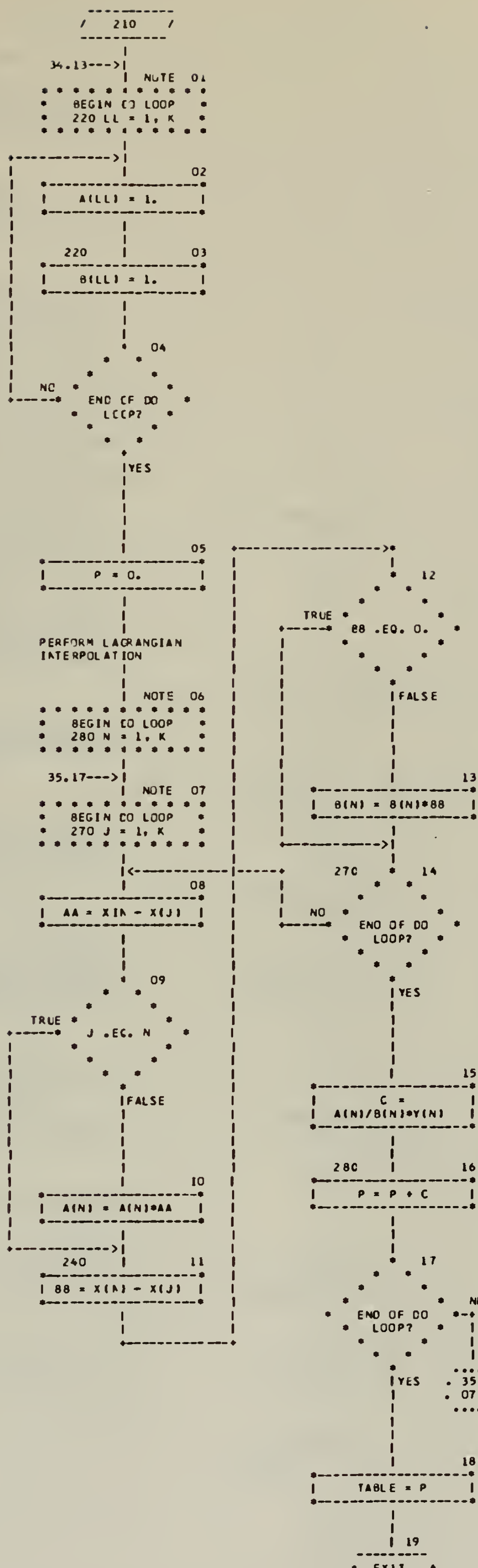

FIGURE 32 SUBROUTINE TABLE FLOW DIAGRAM (CONT.)

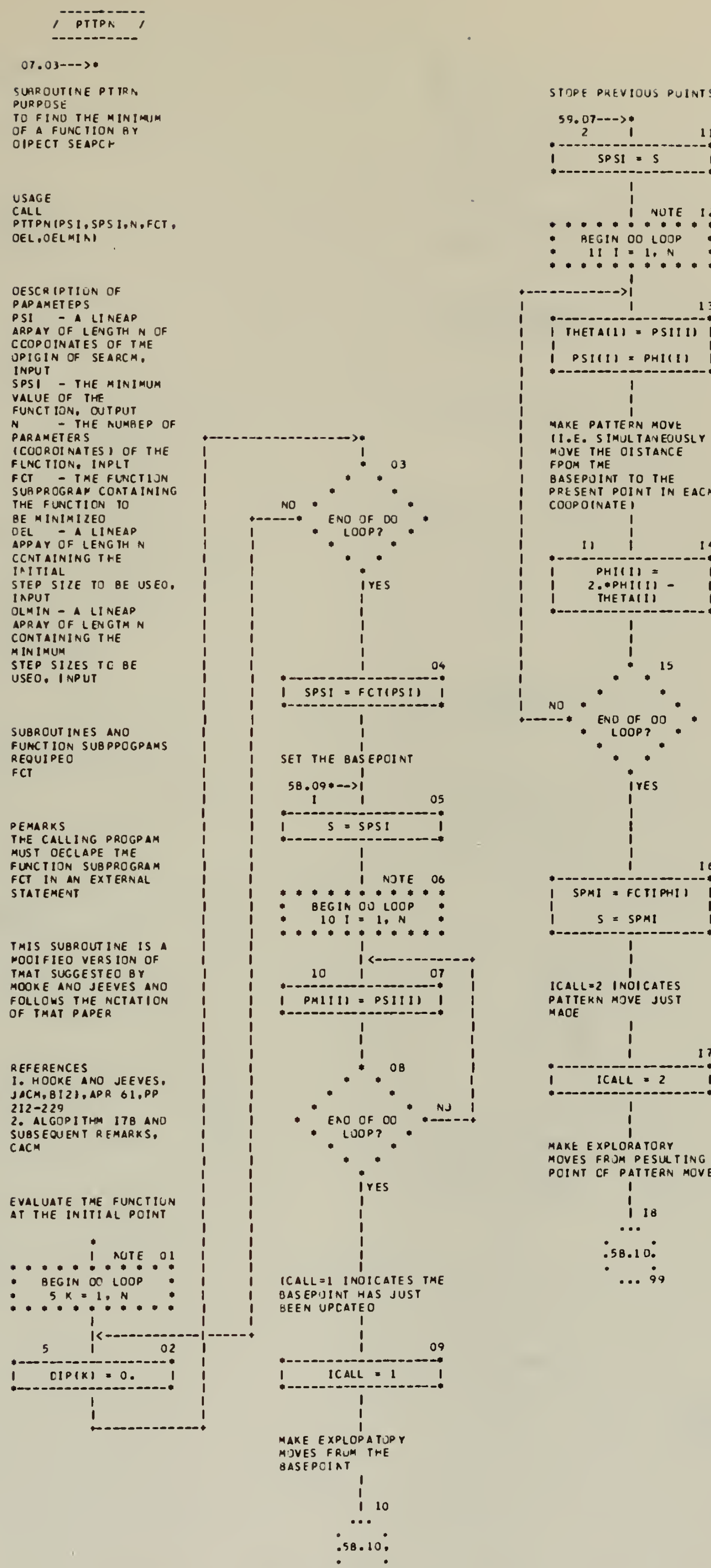

FIGURE 33 SUBROUTINE PTTRN FLOW DIAGRAM

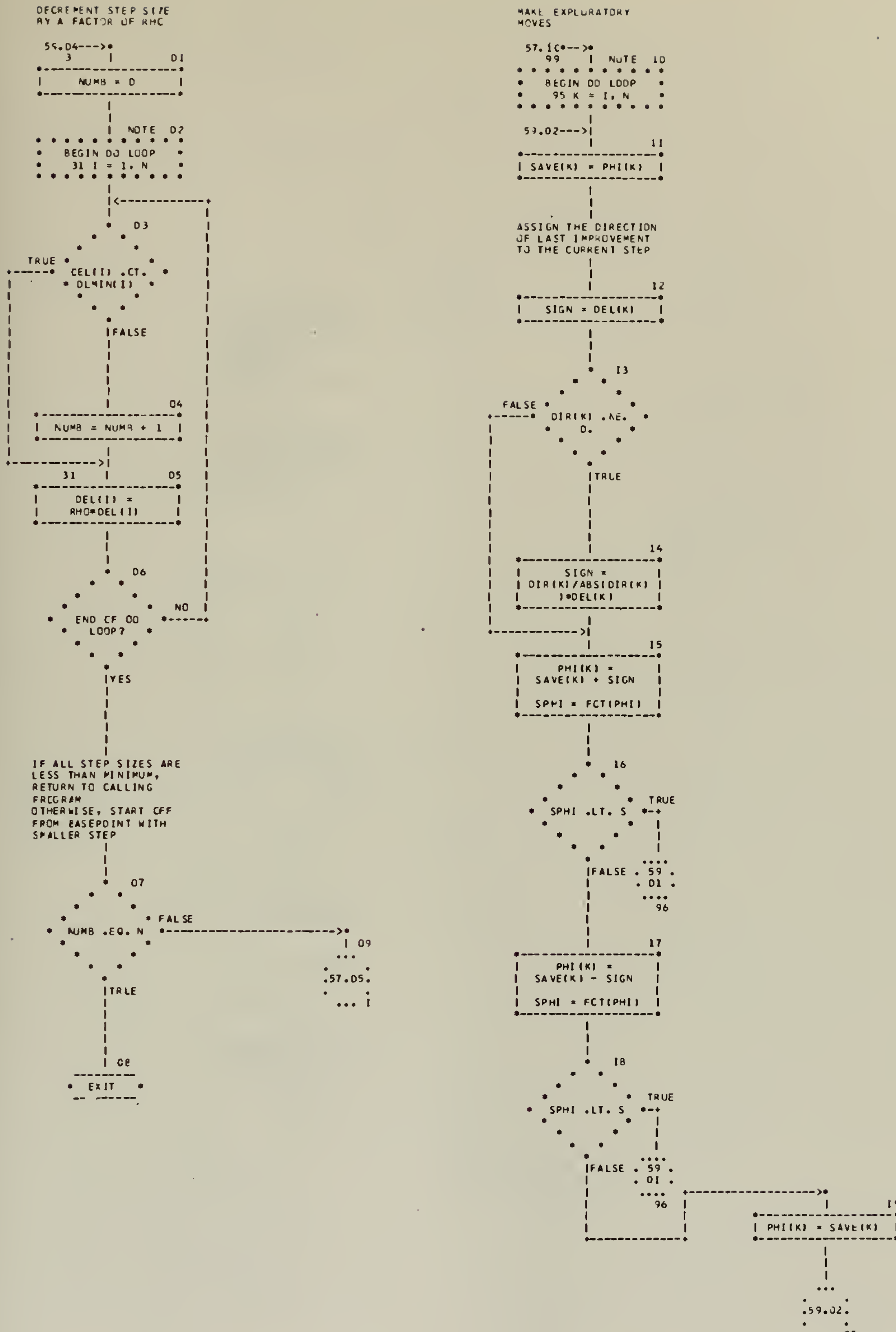

FIGURE 33 SUBROUTINE PTTRN FLOW DIAGRAM (CONT.)

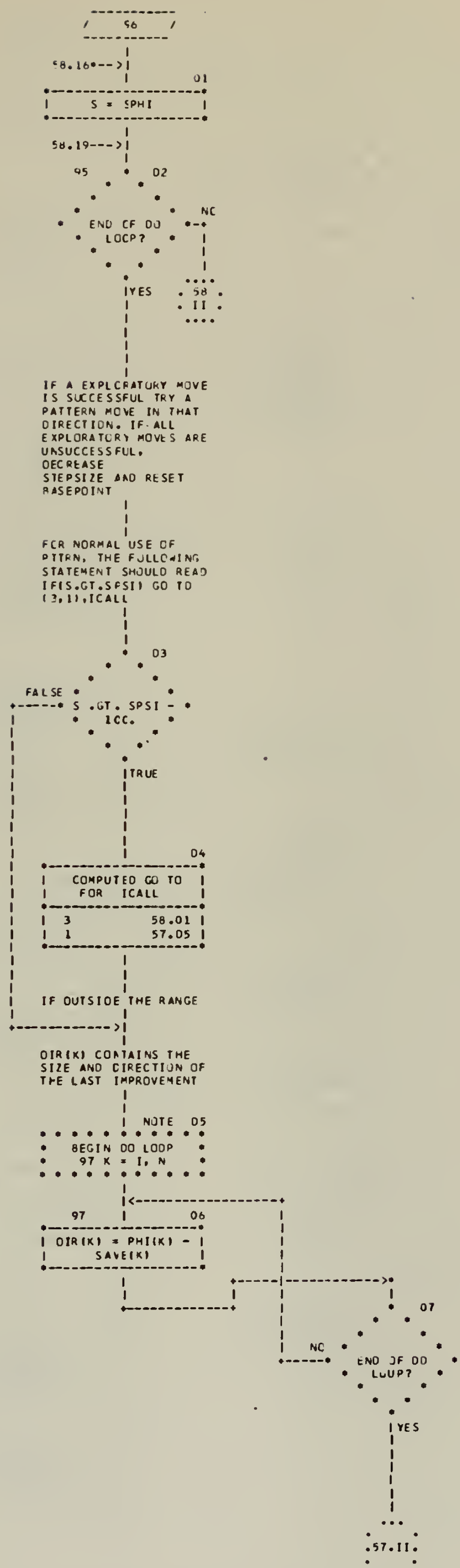

FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM

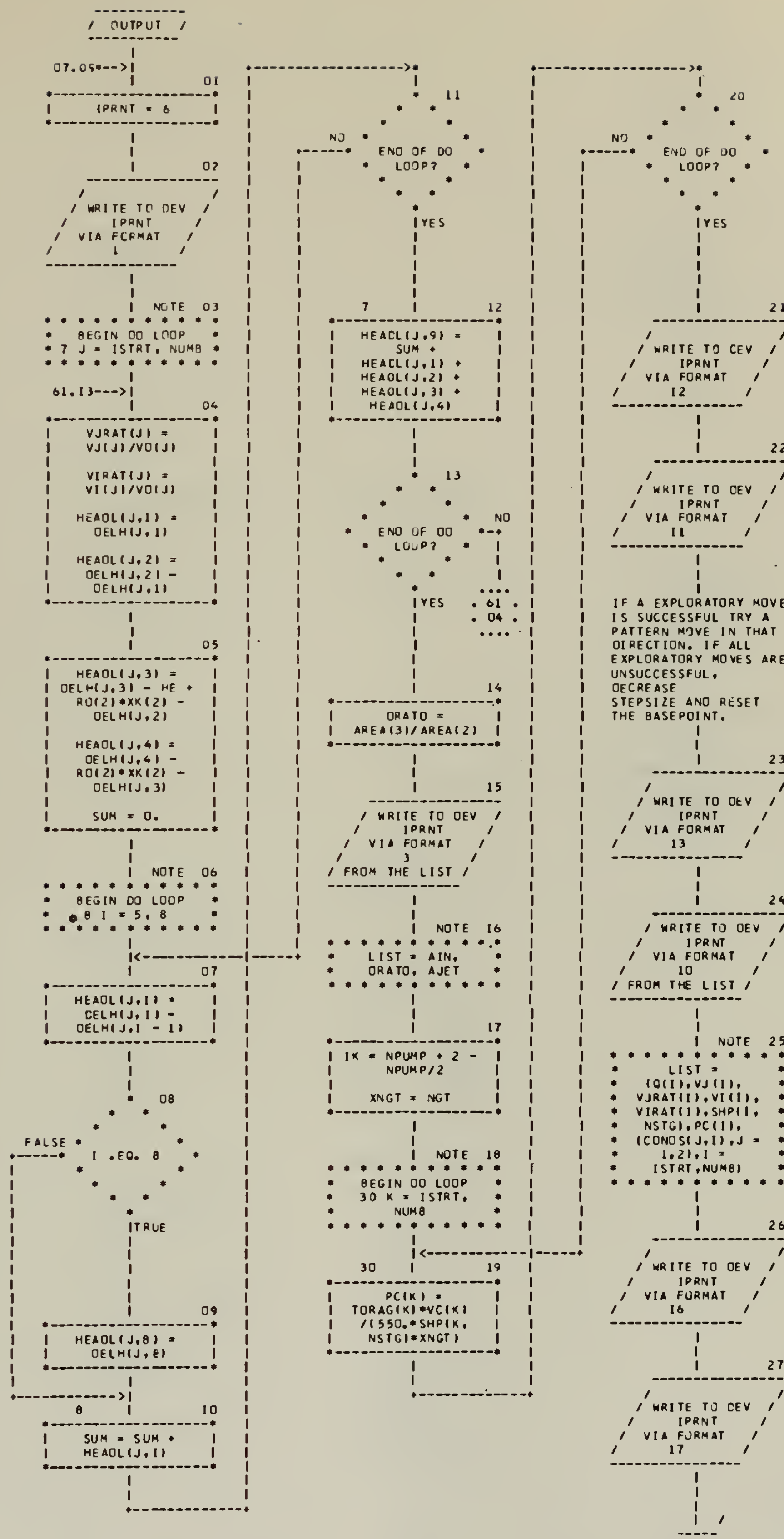

FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM (CONT.)

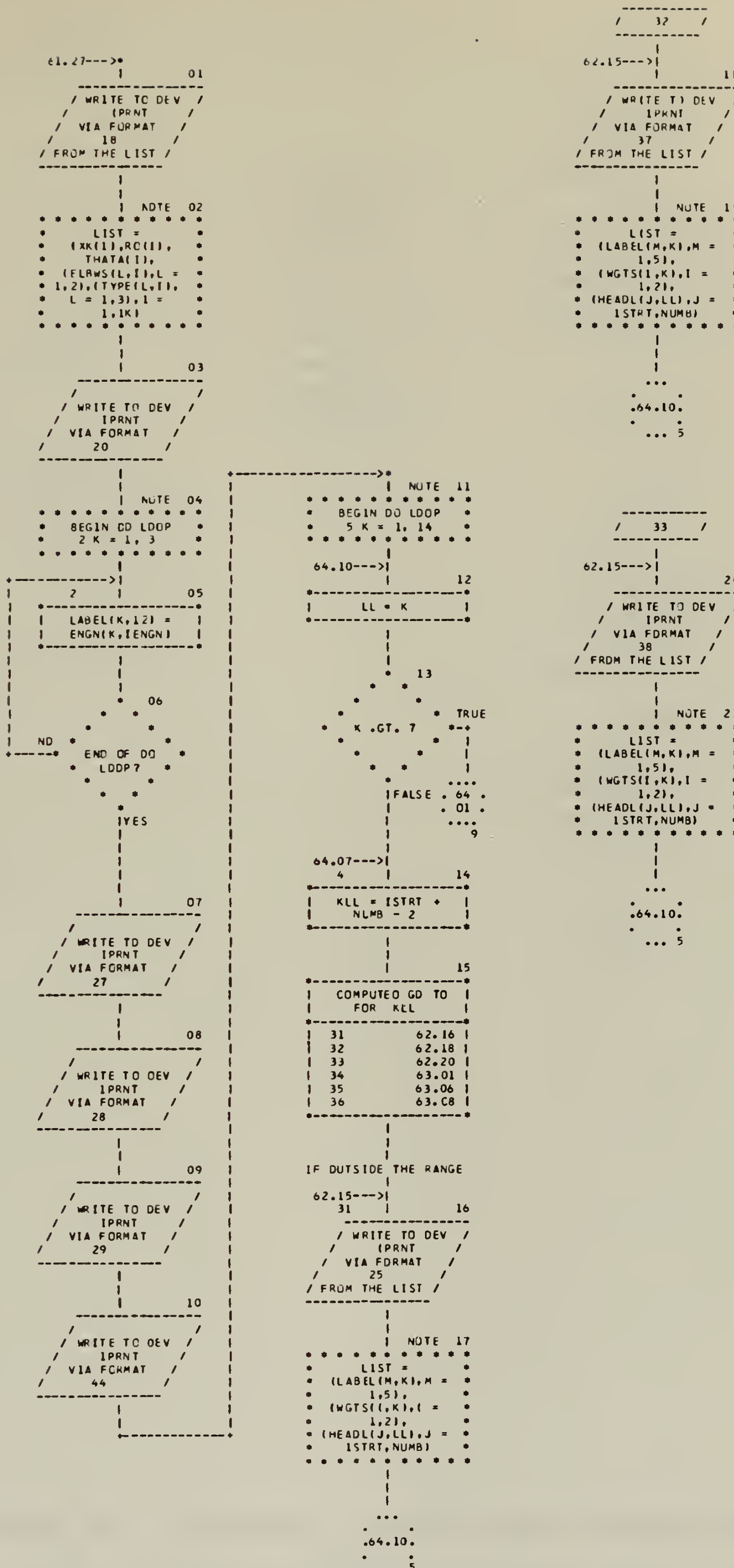

FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM (CONT.)

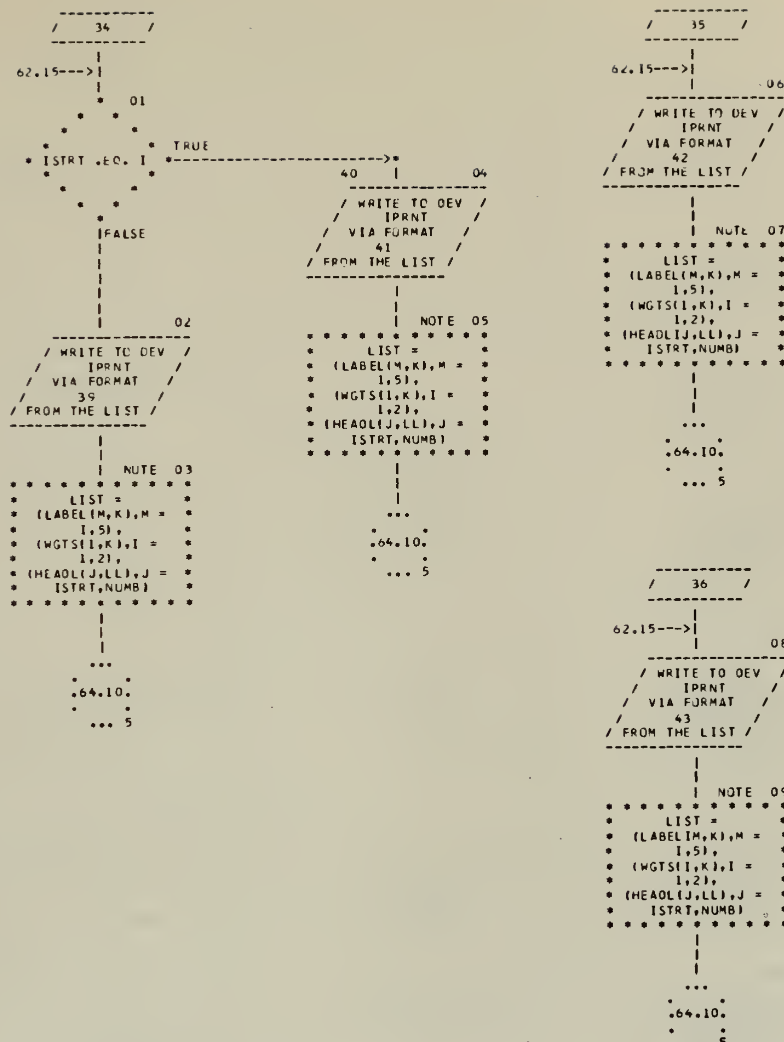

FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM (CONT.)

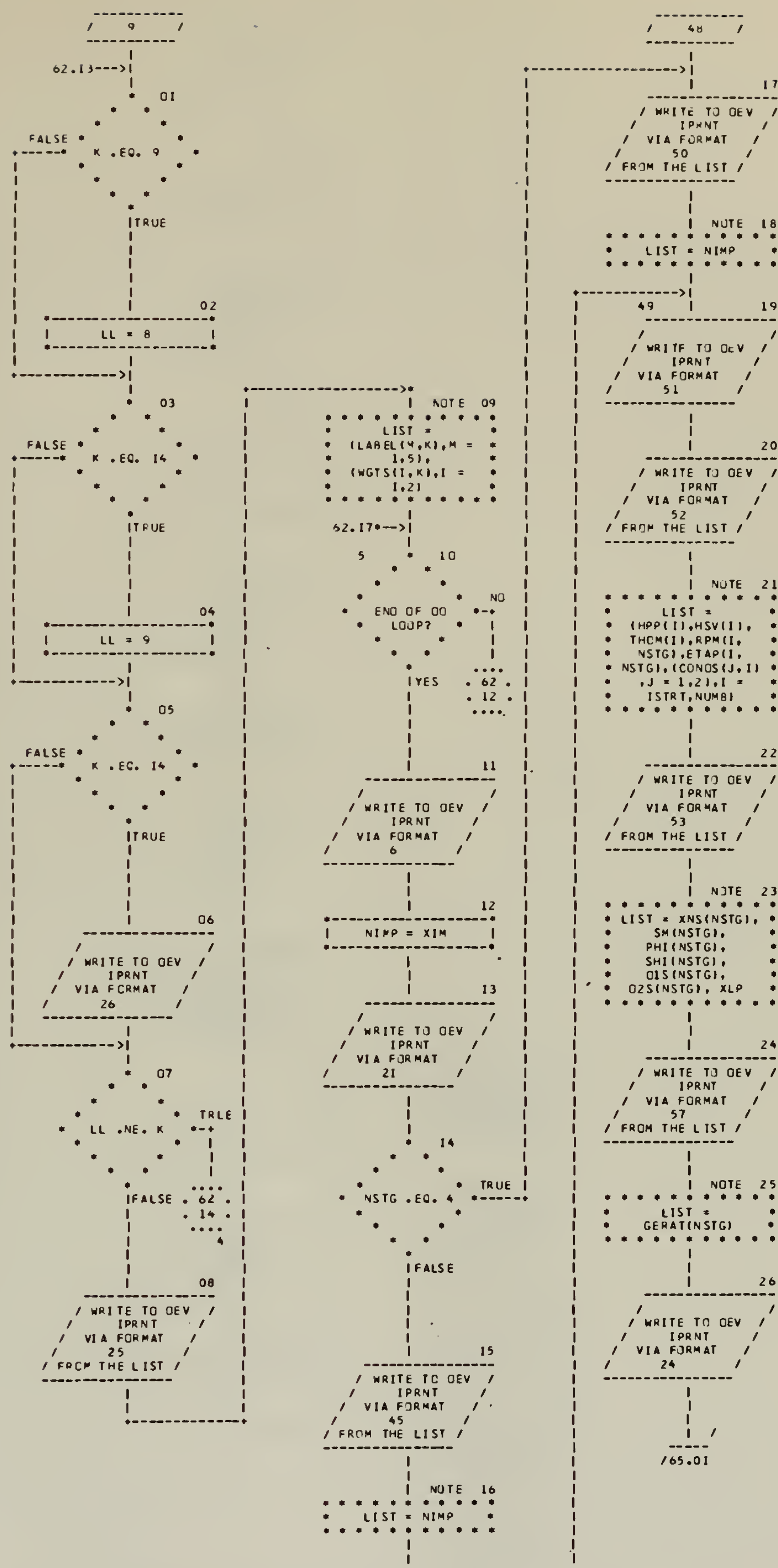

FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM (CONT.)

```
E4.26--->*
         |                  D1
    ----------------
   / WRITE TO DEV  /
  /    IPRNT      /
 /  VIA FORMAT   /
/      54       /
/ FROM THE LIST /
----------------
         |
         | NOTE  D2
* * * * * * * * * * *
* LIST = DRAT, DM,  *
* AI, AIALX, ELEXT, *
*       ELENT       *
* * * * * * * * * * *
         |
         |                  D3
    ----------------
   / WRITE TO DEV  /
  /    IPRNT      /
 /  VIA FORMAT   /
/      55       /
/ FROM THE LIST /
----------------
         |
         | NOTE  D4
* * * * * * * * * * *
* LIST = ELDIF, ELN *
* * * * * * * * * * *
         |
         |                  D5
*-------------------*
|   TFM = TC*CFM    |
*-------------------*
         |
         |                  D6
    ----------------
   / WRITE TO DEV  /
  /    IPRNT      /
 /  VIA FORMAT   /
/      47       /
/ FROM THE LIST /
----------------
         |
         | NOTE  D7
* * * * * * * * * * *
* LIST = TC, T, C,  *
* TI, CI, TFM, CFM  *
* * * * * * * * * * *
         |
         |                  D8
    ----------------
   / WRITE TO DEV  /
  /    IPRNT      /
 /  VIA FORMAT   /
/      56       /
/ FROM THE LIST /
----------------
         |
         | NOTE  D9
* * * * * * * * * * *
*      LIST =       *
* (TDRAG(I),PODI(I),*
* STRTD(I),SPRAY(I) *
* ,(CONDS(J,I),J =  *
*     1,2),I =      *
*    ISTRT,NUMB)    *
* * * * * * * * * * *
         |
         |                  I0
*-------------------*
|      WTRAT =      |
|  (WGTS(1,I4) +    |
| WGTS(2,I4))/DISP  |
*-------------------*
         |
         |                  I1
    ----------------
   / WRITE TO DEV  /
  /    IPRNT      /
 /  VIA FORMAT   /
/      23       /
/ FROM THE LIST /
----------------
         |
         | NOTE  I2
* * * * * * * * * * *
*   LIST = WTRAT    *
* * * * * * * * * * *
         |
         *-------------*

            +------------------->*
                        |                  I3
            *-------------------*
            |      WRATF =      |
            |  (WGTS(1,I4) +    |
            |  WGTS(2,I4) -     |
            | WGTS(2,I1))/DISP  |
            *-------------------*
                        |
                        |                  I4
                   ----------------
                  / WRITE TO DEV  /
                 /    IPRNT      /
                /  VIA FORMAT   /
               /      46       /
              / FROM THE LIST /
              ----------------
                        |
                        | NOTE  I5
            * * * * * * * * * * *
            *   LIST = WRATF    *
            * * * * * * * * * * *
                        |
                        |                  I6
                   ----------------
                  /               /
                 / WRITE TO DEV  /
                /    IPRNT      /
               /  VIA FORMAT   /
              /       6       /
              ----------------
                        |
                        | I7
                    ---------
                    * EXIT  *
                    ---------
```

FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM (CONT.)

```
      LOGICAL IFUEL,IPUMP
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),V0(5),
     1 TRIM(5)
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
      COMMON /CONST/PI,G,RHOD
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)
      COMMON /ELBW/XK(4),PD(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
      COMMON /INDEX/IEVAL,IEOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT
      COMMON /ITABL/L(2)
      COMMON  IFUEL,IPUMP
C
C     SAMPLE INPUT
C
      V0(1)=42.*1.6878
      REST(1)=71000.
      STRTD(1)=3500.
      POD(1)=1750.
      SPRAY(1)=3000.
      POD(2)=500.
      STRTD(2)=1000.
      V0(2)=.5*V0(1)
      SPRAY(2)=750.
      REST(2)=99000.
      RANGE=500.
      BEAM=42.
      IENGN=11
      TRIM(1)=0.
      TRIM(2)=2.
      TEMP=59.
      DISP=[illegible]00.*2240.
      CALL H2OUT
      STOP
      END
```

```
      SUBROUTINE H20JT
      LOGICAL IFUEL,IPUMP
      COMMON /PARMS/ VJVO,VIVO,DIDM
      COMMON /DRAG/TDRAG(5),STRTD(5),PROD(5),SPRAY(5),PEST(5),VD(5),
     1 TRIM(5)
      COMMON /ELBW/XK(4),RD(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
      COMMON /SHIP/ DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
      COMMON /H20/TEMP,PV,RHOW,GNU,HA
      COMMON /TOLER/DELTA
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)
      COMMON /CONST/ PI,G,RHOD
      COMMON /STRTC/TC,T,C,T1,C1,CEM
      COMMON /INDEX/IEVAL,IEOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT
      COMMON /ITABL/L(2)
      COMMON  IFUEL,IPUMP
      EQUIVALENCE (VJVO,PARM(1))
      DIMENSION PARM(3),ENGN(3,12),EHP(5),DEL(4),DLMIN(4)
      DIMENSION VK(5)
      EXTERNAL FCT
      DATA IPRNT/6/
      DATA ENGN/4HTF35,2*4H    ,4HTF40,2*4H    ,4HPROT, 4HEUS ,4H1500,
     A 4HPROT,4HEUS ,4H1000, 4HTYNE,4H 1A ,4H    ,4HTYNE,4H 1C ,4H    ,
     B 4HFT12,4HA   ,4H    ,4HLM15,4H00  ,4H    ,4HLM25,4H00  ,4H    ,
     C 4HFT4A,4H-2C ,4H    ,4HFT4A,4H-12 ,4H    ,4HFT4C,4H-2  ,4H    /
      DATA DLMIN/4*.01/
      IFUEL=.TRUE.
      IPUMP=.FALSE.
      DISPL=DISP/2240.
C     DETERMINE ENGINE TYPE
C     IENGN CONTAINS CODING OF GAS TURBINE MODEL
C
C        IENGN      GAS TURBINE
C
C          1          TF35
C          2          TF40
```

```
C        3        PROTEUS 1500 RPM                                         H20JT037
C        4        PROTEUS 1000 RPM                                         H20JT038
C        5        TYNE 1A                                                  H20JT039
C        6        TYNE 1C                                                  H20JT040
C        7        FT12A                                                    H20JT041
C        8        LM1500                                                   H20JT042
C        9        LM2500                                                   H20JT043
C        10       FT4A-2C                                                  H20JT044
C        11       FT4A-12                                                  H20JT045
C        12       FT4C-2                                                   H20JT046
C                                                                          H20JT047
C     DETERMINE WHICH POINTS ARE INPUT                                     H20JT048
C                                                                          H20JT049
      ISTRT=1                                                              H20JT050
      NUMB=2                                                               H20JT051
      IF(IEVAL.EQ.0) GO TO 3                                               H20JT052
      NUMB=2+IABS(IEVAL)                                                   H20JT053
      IF(IEVAL.LT.0) ISTRT=3                                               H20JT054
    3 DO 1 I=ISTRT,NUMB                                                    H20JT055
      VK(I)=VO(I)*.592487                                                  H20JT056
    1 TDRAG(I)=POD(I)+STRTD(I)+SPRAY(I)+REST(I)                            H20JT057
C                                                                          H20JT058
C     IEVAL.LT.0 IMPLIES NO CRUISE OR TAKE-OFF POINTS SPECIFIED,           H20JT059
C     ABS(IEVAL) INDICATES HOW MANY POINTS FOR PERFORMANCE ESTIMATION      H20JT060
C     IEVAL.EQ.0 IMPLIES DESIGN AT CRUISE AND TAKE-OFF ONLY                H20JT061
C     IEVAL.GT.0 IMPLIES DESIGN AT CRUISE/TAKE-OFF AND ESTIMATE PERFORM.H20JT062
C     AT IEVAL POINTS                                                      H20JT063
C     IF ENTERED, CRUISE POINTS ARE IN FIRST POSITION IN ARRAY, TAKE-OFFH20JT064
C     POINTS IN SECOND AND PERFORMANCE ESTIMATION POINTS IN REMAINING      H20JT065
C     POSITIONS                                                            H20JT066
C     IEQPT NON-ZERO IMPLIES SPECIFIC TYPE EQUIPMENT TO BE INPUT BY USERH20JT067
C     THIS SECTION OF THE PROGRAM TO BE WRITTEN LATER                      H20JT068
      IF(ISTRT.NE.1) GO TO 6                                               H20JT069
      WRITE(IPRNT,5)                                                       H20JT070
    5 FORMAT(1H1,10X,58H *** WATERJET PROPULSION SYSTEM DESIGN AND PERFOH20JT071
     ARMANCE ***,///)                                                      H20JT072
```

```
      WRITE(IPRNT,31)                                                   H20JT073
      WRITE(IPRNT,6)                                                    H20JT074
    6 FORMAT(12H OPERATIONAL,/)                                         H20JT075
      WRITE(IPRNT,7)                                                    H20JT076
    7 FORMAT(30X,6HCRUISE,15X,8HTAKE-OFF,/)                             H20JT077
      WRITE(IPRNT,8) (VK(N),N=1,2)                                      H20JT078
    8 FORMAT(16H VELOCITY, KNOTS,14X,F5.1,17X,F5.1)                     H20JT079
      WRITE(IPRNT,9) (TDRAG(N),N=1,2)                                   H20JT080
    9 FORMAT(16H TOTAL DRAG, LBS,13X,F7.0,15X,F7.0)                     H20JT081
      WRITE(IPRNT,10) (TRIM(N),N=1,2)                                   H20JT082
   10 FORMAT(25H ANGLE OF ATTACK, DEGREES,6X,F4.1,18X,F4.1,//)          H20JT083
      IF(IEVAL.EQ.0) GO TO 11                                           H20JT084
      WRITE(IPRNT,12)                                                   H20JT085
   12 FORMAT(/,48H PERFORMANCE EVALUATION AT THE FOLLOWING POINTS,/)    H20JT086
      GO TO 13                                                          H20JT087
    4 WRITE(IPRNT,14)                                                   H20JT088
   14 FORMAT(1H1,10X,47H *** WATERJET PROPULSION SYSTEM PERFORMANCE ***,H20JT089
     A ///)                                                             H20JT090
   13 IM=IABS(IEVAL)                                                    H20JT091
      WRITE(IPRNT,6)                                                    H20JT092
      DO 15 I=1,IM                                                      H20JT093
      J=I+2                                                             H20JT094
   15 WRITE(IPRNT,16) VK(J),TDRAG(J),TRIM(J)                            H20JT095
   16 FORMAT(16H VELOCITY, KNOTS,14X,F5.1,/,16H TOTAL DRAG,LBS,13X,F7.0,H20JT096
     A /,25H ANGLE OF ATTACK, DEGREES,6X,F4.1,//)                       H20JT097
      WRITE(IPRNT,31)                                                   H20JT098
   31 FORMAT(22H CRAFT CHARACTERISTICS,//)                              H20JT099
   11 WRITE(IPRNT,17)                                                   H20JT100
   17 FORMAT(14H CONFIGURATION,/)                                       H20JT101
      WRITE(IPRNT,18) BEAM,DISPL,RANGE,(ENGN(N,IENGN),N=1,3)            H20JT102
   18 FORMAT(28H AVERAGE BEAM, FEET.........., F7.1,/,28H DISPLACEMENT, LH20JT103
     AONG TONS...., F7.0,/,28H ENDURANCE, NM..............,F7.0,/, 28H GAH20JT104
     BS TURBINE PLANT...........,3X,3A4,//)                             H20JT105
      WRITE(IPRNT,19) HS,HE,HCL,XLS,XLPE                                H20JT106
   19 FORMAT(48H DEPTH OF SUBMERGENCE OF NACELLE.................,F5.1, 2XH20JT107
     A,4HFEET,/,48H HEIGHT OF PUMP CENTERLINE ABOVE MEAN WATER.....,F5.1H20JT108
```

```
     B,2X,4HFEET,/,49H HEIGHT OF PUMP CENTERLINE ABOVE KEEL............, H20JT109
     CF5.1,2X,4HFEET,/,48H DISTANCE OF STRUT FROM TRANSOM...............H20JT110
     D...,F5.1,2X,4HFEET,/,49H DISTANCE OF PUMP EXIT FROM TRANSOM........H20JT111
     E.....,F5.1,2X,4HFEET,//)                                           H20JT112
      WRITE(IPRNT,20)                                                    H20JT113
   20 FORMAT(10X,17H WATER PROPERTIES,/,10X,45H (ASSUMES STANDARD(3.5% SH20JT114
     1ALINITY) SALT WATER),//)                                           H20JT115
C                                                                        H20JT116
C     TEMP IS THE TEMPERATURE OF THE WATER IN DEGREES FAHRENHEIT         H20JT117
C                                                                        H20JT118
   25 PV=.11413E-7*TEMP**4+.12435E-6*TEMP**3+.49859E-4*TEMP*TEMP+.29719EH20JT119
     A-2*TEMP+.032335                                                    H20JT120
      GNU=EXP(-.6201E-6*TEMP**3+.1749E-3*TEMP*TEMP-.02796*TEMP+1.414)*   H20JT121
     A 1.E-5                                                             H20JT122
      RHOW=(-.79965E-6*TEMP**4+.13714E-3*TEMP**3-.01982*TEMP*TEMP+.5617H20JT123
     A*TEMP+56.569)/G                                                    H20JT124
      HA=2117./(RHOW*G)                                                  H20JT125
      WRITE(IPRNT,21) TEMP,RHOW,GNU,PV                                   H20JT126
   21 FORMAT(32H TEMPERATURE, DEGREES FAHRENHEIT,5X,F4.0,/,              H20JT127
     A 28H DENSITY, LBF-SEC**2/FEET**4,9X,F6.3,/,                        H20JT128
     B 31H VISCOSITY, *10**5, FEET**2/SEC,6X,5PF6.3,/,                   H20JT129
     C 21H VAPOR PRESSURE, FEET,16X,0PF6.3,//)                           H20JT130
      WRITE(IPRNT,22) G                                                  H20JT131
   22 FORMAT(36H ACCELERATION OF GRAVITY, FT/SECS**2,6X,F7.3,//)         H20JT132
      IF(IFOPT.NE.0) GO TO 23                                            H20JT133
      WRITE(IPRNT,24)                                                    H20JT134
   24 FORMAT(69H NO EQUIPMENTS OR CONFIGURATIONS SPECIFIED. GENERATED ASH20JT135
     A PER PROGRAM,/,1H1)                                                H20JT136
      GO TO 32                                                           H20JT137
   33 WRITE(IPRNT,34) (ENGN(I,IENGN),I=1,3)                              H20JT138
   34 FORMAT(16H MORE THAN FOUR ,2A4,30H REQUIRED. INVALID PRIME MOVER) H20JT139
      RETURN                                                             H20JT140
   35 WRITE(IPRNT,36)                                                    H20JT141
   36 FORMAT(//,67HONE ENGINE DRIVEN AT LESS THAN HALF DESIGN SHP.INVALIH20JT142
     1D PRIME MOVER,//)                                                  H20JT143
      RETURN                                                             H20JT144
```

```
   23 WRITE(IPRNT,26)                                                     H20JT145
   26 FORMAT(1H1,' THE FOLLOWING EQUIPMENT, ETC. SPECIFIED.....')         H20JT146
C                                                                         H20JT147
C     LATER THE SECTION FOR OUTPUTTING THE SPECIFIED EQUIPMENTS ETC WILLH20JT148
C     HAVE TO BE PUT IN HERE                                              H20JT149
C                                                                         H20JT150
C     COMMENCE DESIGN/PERFORMANCE PREDICTION                              H20JT151
C                                                                         H20JT152
C                                                                         H20JT153
C     FIRST CHECK ON MINIMUM NUMBER OF GAS TURBINES REQUIRED, GIVEN THE H20JT154
C     TYPE AND EHP. THEN CYCLE THROUGH THE PUMP COMBINATIONS POSSIBLE.  H20JT155
C                                                                         H20JT156
   32 IF(ISTRT.NE.1) GO TO 38                                             H20JT157
      IN=1                                                                H20JT158
      MAX=3                                                               H20JT159
      ISAVE=4                                                             H20JT160
      XMIN=.25                                                            H20JT161
      DO 37 IK=ISTRT,NUMB                                                 H20JT162
      IL=1                                                                H20JT163
      EHP(IK)=TDRAG(IK)*VO(IK)/550.                                       H20JT164
      DO 37 IJ=1,3                                                        H20JT165
      XJ=IJ+IJ/3                                                          H20JT166
      IM=IK/3                                                             H20JT167
      MK=IK-IM*(IK-2)                                                     H20JT168
      IF(1.5*EHP(IK).GT.XJ*PERF(MK,IENGN)) IL=IJ+1                        H20JT169
      IF(IK.GT.1) GO TO 39                                                H20JT170
      IF(EHP(IK)/XJ.LT.XMIN*PERF(1,IENGN)) ISAVE=XJ*.5                    H20JT171
      IF(ISAVE.LT.MAX) MAX=ISAVE                                          H20JT172
      IF(MAX.EQ.0) GO TO 35                                               H20JT173
   39 IF(IL.GT.3) GO TO 33                                                H20JT174
   37 IF(IN.LT.IL) IN=IL                                                  H20JT175
      DO 30 IK=IN,MAX                                                     H20JT176
C                                                                         H20JT177
C     PUT MIN NUMBER GT'S REQUIRED IN HERE                                H20JT178
      NGT=IK+IK/3                                                         H20JT179
      KM=NGT/4+1                                                          H20JT180
```

```
      K1=2*IK-NGT+1                                                      H20JT181
      DO 28  I=KM,K1                                                     H20JT182
      DELTA=.05                                                          H20JT183
      DEL(1)=.5                                                          H20JT184
      DEL(2)=.2                                                          H20JT185
      DEL(3)=.3                                                          H20JT186
      NPUMP=I+I/3                                                        H20JT187
      VIVO=1.8                                                           H20JT188
      VIVO=.7                                                            H20JT189
      DIDM=.7                                                            H20JT190
      CALL PTTRN(PARM,WEIGT,3,FCT,DEL,DLMIN)                             H20JT191
      DELTA=0.0                                                          H20JT192
      WEIGT=FCT(PARM)/2240.                                              H20JT193
      WRITE(IPRNT,50) WEIGT                                              H20JT194
   50 FORMAT(10X,21H*** SYSTEM WEIGHT IS ,F10.2,9H TONS ***)             H20JT195
      WRITE(IPRNT,51) NGT,NPUMP                                          H20JT196
   51 FORMAT(//,27H NUMBER OF GAS TURBINES IS ,I2,/,20H NUMBER OF PUMPS  H20JT197
     AIS ,I2,//)                                                         H20JT198
      CALL OUTPUT                                                        H20JT199
   28 CONTINUE                                                           H20JT200
   30 CONTINUE                                                           H20JT201
      IF(NUMB.EQ.2) RETURN                                               H20JT202
      ISTRT=3                                                            H20JT203
   38 WEIGT=FCT(PARM)/2240.                                              H20JT204
      WRITE(IPRNT,50) WEIGT                                              H20JT205
      WRITE(IPRNT,51) NGT,NPUMP                                          H20JT206
      CALL OUTPUT                                                        H20JT207
      RETURN                                                             H20JT208
      END                                                                H20JT209
```

```
      FUNCTION FCT(PARM)
      LOGICAL IFUEL,IPUMP
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA
      COMMON /ELBW/XK(4),RR(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
      COMMON /SHIP/ DISP,RANGE,BEAM,HS,HF,HCL,XLS,XLPE,XLP
      COMMON /NACLL/PRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)
      COMMON /CONST/PI,G,RHOD
      COMMON /PUMM/QQ(5),D1S(5),D2S(5),XNS(5),SM(5),PLP(5),NSTG,SHI(5),
     A XIM
      COMMON /DRAG/TDRAG(5),STRTD(5),PODD(5),SPRAY(5),REST(5),VQ(5),
     1 TRIM(5)
      COMMON /CDRAG/CSTRT(5),CPOD(5),CSPRY(5)
      COMMON /TOLER/ DELTA
      COMMON /INDEX/IEVAL,IEOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT
      COMMON /ITAPL/L(2)
      COMMON IFUEL,IPUMP
      DIMENSION PARM(4),APOD(5),ASTRT(5),ASPRY(5),C(5),DDRAG(5),DSPRY(5)
     A ,DSTRT(5),DPOD(5)
      DATA C/1.,1.25,3*1./
      IF(.NOT.IPUMP) XLP=5.
      TSUM=1.E50
C
C     POP BACK TO OPTIMIZATION IF BOUNDS EXCEEDED
C
      IF(PARM(1).GT.5..AND.DELTA.GT.1.E-9) GO TO 8
      IF(PARM(1).LT.1.1) GO TO 8
      IF(PARM(2).LT..5) GO TO 8
      IF(PARM(2).GT.1.5) GO TO 8
      IF(PARM(3).GT..9) GO TO 8
      IF(PARM(3).LE.0..AND.DELTA.GT.1.E-9) GO TO 8
      DRAT=PARM(3)
      DO 15 J=ISTRT,NUMB
      DSTRT(J)=STRTD(J)
```

```
      DPOD(J)=POD(J)                                                    FCT 0037
      DSPRY(J)=SPRAY(J)                                                 FCT 0038
   15 DDRAG(J)=TDRAG(J)                                                 FCT 0039
      VJ(1)=VO(1)*PARM(1)                                               FCT 0040
      VI(1)=VO(1)*PARM(2)                                               FCT 0041
   10 ANGLE=ATAN(TDRAG(1)/DISP)                                         FCT 0042
      IF(TDRAG(1)/DISP.GT..2.AND.DELTA.GT.1.E-9) GO TO 8                FCT 0043
      IF(TDRAG(1)/DISP.LT..05.AND.DELTA.GT.1.E-9) GO TO 8               FCT 0044
      COEF=1.                                                           FCT 0045
      Q(1)=TDRAG(1)/(RHOW*(VJ(1)*COS(ANGLE)-VO(1)))                     FCT 0046
      AIN=Q(1)/VI(1)                                                    FCT 0047
      AJET=Q(1)/VJ(1)                                                   FCT 0048
      I=2                                                               FCT 0049
      IF(ISTRT.EQ.3) I=3                                                FCT 0050
      DO 5 J=I,NUMB                                                     FCT 0051
      SPD=.5*VO(J)/COS(ANGLE)                                           FCT 0052
      VJ(J)=SPD+SQRT(SPD*SPD+C(J)*TDRAG(J)/(RHOW*AJET*COS(ANGLE)))      FCT 0053
      Q(J)=AJET*VJ(J)                                                   FCT 0054
      VI(J)=Q(J)/AIN                                                    FCT 0055
      ICOMP=1                                                           FCT 0056
      CALL NACEL                                                        FCT 0057
      IF(WGTS(1,1).GT.DISP.AND.DELTA.GT.1.E-9) GO TO 8                  FCT 0058
      ICOMP=2                                                           FCT 0059
      DEPTH=SQRT(AREA(1))                                               FCT 0060
      WIDTH=.5*DEPTH                                                    FCT 0061
      CALL ELBOW                                                        FCT 0062
      CGS(1,ICOMP)=HCL-HE-HS                                            FCT 0063
      CGS(2,ICOMP)=XLS+(HE-RO(1)*XK(1)+HS)/TAN(THATA(2)*.0174533)       FCT 0064
      WGTS(1,ICOMP)=WGTS(1,ICOMP)*(RHOD-RHOW)/RHOD                      FCT 0065
      WGTS(2,ICOMP)=0.                                                  FCT 0066
   12 ICOMP=3                                                           FCT 0066
      CALL STRUT                                                        FCT 0067
      J=NUMB                                                            FCT 0068
      IF(ISTRT.EQ.1) J=2                                                FCT 0069
C                                                                       FCT 0070
C     SEE IF NEWLY COMPUTED DRAG DIFFERS SIGNIFICANTLY (I.E. GREATER    FCT 0071
```

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C     THAN 5%) FROM PREVIOUS ESTIMATE. IF SO, RECOMPUTE ON BASIS OF NEW FCT 0072
C     DRAG. OTHERWISE CONTINUE.                                         FCT 0073
C                                                                       FCT 0074
      JDRAG=1                                                           FCT 0075
      DO 9 I=ISTRT,J                                                    FCT 0076
      APOD(I)=COEF*(CPOD(I)-POD(I))                                     FCT 0077
      ASTRT(I)=CSTRT(I)-STRTD(I)                                        FCT 0078
      ASPRY(I)=CSPRY(I)-SPRAY(I)                                        FCT 0079
      IF(ABS(APOD(I)+ASTRT(I)+ASPRY(I)).GE..05*TDRAG(I)) JDRAG=2        FCT 0080
      SPRAY(I)=CSPRY(I)                                                 FCT 0081
      STRTD(I)=CSTRT(I)                                                 FCT 0082
      POD(I)=CPOD(I)                                                    FCT 0083
    9 TDRAG(I)=REST(I)+POD(I)+STRTD(I)+SPRAY(I)                         FCT 0084
      IF(JDRAG.EQ.2) GO TO 10                                           FCT 0085
      ICOMP=4                                                           FCT 0086
      CALL ELBOW                                                        FCT 0087
      CGS(1,ICOMP)=HCL                                                  FCT 0088
      CGS(2,ICOMP)=XLS                                                  FCT 0089
      CGS(3,ICOMP)=CGS(1,ICOMP)                                         FCT 0090
      CGS(4,ICOMP)=XLS                                                  FCT 0091
      ICOMP=5                                                           FCT 0092
      GO TO (1,2,3,3),NPUMP                                             FCT 0093
    1 CALL JUNCT                                                        FCT 0094
      GO TO 4                                                           FCT 0095
    2 CALL PIPE                                                         FCT 0096
      GO TO 4                                                           FCT 0097
    3 CALL DIVRG                                                        FCT 0098
    4 ICOMP=9                                                           FCT 0099
      DSIG=4.                                                           FCT 0100
      DO 13 KOUNT=ISTRT,NUMB                                            FCT 0101
      TOTAL=VO(KOUNT)**2/G*.5-DELH(KOUNT,6)-PV+HA                       FCT 0102
      SIGMA=TOTAL-(Q(KOUNT)/AREA(6))**2*.5/G                            FCT 0103
      IF(SIGMA.GT.0.) GO TO 13                                          FCT 0104
      IF(SIGMA.GT.DSIG) GO TO 13                                        FCT 0105
      COEF=0.                                                           FCT 0106
      DSIG=SIGMA                                                        FCT 0107
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      AREA(4)=1.05*Q(KOUNT)/SQRT(2.*G*TOTAL)                            FCT 0108
   13 CONTINUE                                                          FCT 0109
      IF(DSIG.NE.4.) GO TO 12                                           FCT 0110
   14 CONTINUE                                                          FCT 0111
      CALL NOZZL                                                        FCT 0112
      IF(WGTS(1,ICOMP).GT.DISP.AND.DELTA.GT.1.E-9) GO TO 8              FCT 0113
      ICOMP=0                                                           FCT 0114
      CALL PUMP                                                         FCT 0115
      IF(IPUMP) NNSTG=NSTG                                              FCT 0116
      IF(IPUMP) GO TO 12                                                FCT 0117
      IF(NNSTG.NE.NSTG.AND.DELTA.LT.1.E-9) IPUMP=.TRUE.                 FCT 0118
      IF(NNSTG.NE.NSTG.AND.DELTA.LT.1.E-3) GO TO 12                     FCT 0119
      DO 11 J=ISTRT,NUMB                                                FCT 0120
   11 DELH(J,9)=DELH(J,7)+DELH(J,8)                                     FCT 0121
      ZSUM=0.                                                           FCT 0122
      XSUM=0.                                                           FCT 0123
      TSUM=0.                                                           FCT 0124
      WGTS(1,12)=PERF(5,IENGN)*FLOAT(NGT)                               FCT 0125
      DO 6 J=1,2                                                        FCT 0126
      SUM=0.                                                            FCT 0127
      SUMX=0.                                                           FCT 0128
      SUMZ=0.                                                           FCT 0129
      DO 7 I=1,12                                                       FCT 0130
      SUMZ=SUMZ+WGTS(J,I)*CGS(2*J-1,I)                                  FCT 0131
      SUMX=SUMX+WGTS(J,I)*CGS(2*J,I)                                    FCT 0132
    7 SUM=SUM+WGTS(J,I)                                                 FCT 0133
      WGTS(J,14)=SUM                                                    FCT 0134
      CGS(2*J-1,13)=SUMZ/SUM                                            FCT 0135
      CGS(2*J,13)=SUMX/SUM                                              FCT 0136
      TSUM=TSUM+SUM                                                     FCT 0137
      XSUM=XSUM+SUMX                                                    FCT 0138
    6 ZSUM=ZSUM+SUMZ                                                    FCT 0139
      CGSX=XSUM/TSUM                                                    FCT 0140
      CGSZ=ZSUM/TSUM                                                    FCT 0141
      WGTS(2,13)=-RHOW*Q(1)*VJ(1)*SIN(ANGLE)                            FCT 0142
      WGTS(2,14)=WGTS(2,14)+WGTS(2,13)                                  FCT 0143
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  8 FCT=TSUM+WGTS(2,13)                                         FCT 0144
    IF(FCT.LT.DISP.OR.DELTA.LT.1.E-5) RETURN                    FCT 0145
    DO 16 I=ISTRT,NUMB                                          FCT 0146
    SPRAY(I)=DSPRY(I)                                           FCT 0147
    PCD(I)=DPCD(I)                                              FCT 0148
    STRTD(I)=DSTRT(I)                                           FCT 0149
 16 TDRAG(I)=DDRAG(I)                                           FCT 0150
    RETURN                                                      FCT 0151
    END                                                         FCT 0152
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      SUBROUTINE NACEL                                                  NACEL000
      COMMON /WARN/CAV(5)                                               NACEL001
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   NACEL002
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP               NACEL003
      COMMON /CONST/PI,G,RHOD                                           NACEL004
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           NACEL005
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   NACEL006
      COMMON /INDEX/IEVAL,IEOPT,ISTRT,NJMB,IENGN,ITYPE,ICOMP,NPUMP,NGT  NACEL007
      COMMON /DRAG/TDRAG(5),STRTD(5),PDD(5),SPRAY(5),REST(5),VQ(5),     NACEL008
     1 TRIM(5)                                                          NACEL009
      COMMON /CDRAG/CSTRT(5),CPOD(5),CSPRY(5)                           NACEL010
      COMMON /TOLER/DELTA                                               NACEL011
      COMMON /NACLL/DRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN         NACEL012
      COMMON /ELBW/XK(4),RD(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           NACEL013
      DIMENSION NL(2),ML(2),KL(2),JL(2),IL(2)                           NACEL014
      DIMENSION AA(30),AB(30),AC(30),AD(30),AE(30),AF(30),AG(30),AH(30) NACEL015
      DIMENSION BA(30),BB(30),BC(30),BD(30),BE(30),BF(30),BG(30),BH(30) NACEL016
      DIMENSION ALFAT(4),VRT(6), XDT(10),CPINT(6,10,4),CPEXT(6,10,4),   NACEL017
     1PRLT(6),SIGI(5),PTO(5),XDTT(4),CDUMX(10),  CDUMY(10),  AT(2),CD(5)NACEL018
     2,DIDMT(10),VRTT(4),DLIP(5),Q1(5),VELP(5),VRTEX(4),VRMAX(5)        NACEL019
      EQUIVALENCE (CPINT(1,1,1),AA(1)),(CPINT(1,6,1),AB(1)),(CPINT(1,1,2NACEL020
     1),AC(1)),(CPINT(1,6,2),AD(1)),(CPINT(1,1,3),AE(1)),(CPINT(1,6,3), NACEL021
     2AF(1)),(CPINT(1,1,4),AG(1)),(CPINT(1,6,4),AH(1)),(CPEXT(1,1,1),BA(NACEL022
     31)),(CPEXT(1,6,1),BB(1)),(CPEXT(1,1,2),BC(1)),(CPEXT(1,6,2),BD(1))NACEL023
     4,(CPEXT(1,1,3),BE(1)),(CPEXT(1,6,3),BF(1)),(CPEXT(1,1,4),BG(1)),  NACEL024
     5(CPEXT(1,6,4),BH(1))                                              NACEL025
      EQUIVALENCE (AT(1),ALFAT(1)),(DRAT,DIDM)                          NACEL026
      DATA NL,ML,KL,JL/6, 2,2*2,10,3,6,3/,IL/4,2/                       NACEL027
      DATA PRLT/0.973,0.963,0.962,0.945,0.928,0.902/                    NACEL028
      DATA ALFAT/0.0,2.0,4.0,6.0/,                                      NACEL029
     1 XDT/0.25,0.50,0.75,1.0,1.25,1.50,1.75,2.0,2.25,2.5/,DIDMT/0.810, NACEL030
     2 0.695,0.627,0.577,0.533,0.490,0.439,0.365,0.260,0.090/           NACEL031
     3, VRT/.7,.8,.9,1.05,1.15,1.25/                                    NACEL032
      DATA AA/                                                          NACEL033
     A  0.170  , -0.150  , -0.540  , -1.300  , -1.980  , -2.770  ,      NACEL034
     B  0.267  ,  0.010  , -0.300  , -0.860  , -1.330  , -1.925  ,      NACEL035
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     C 0.335  ,  0.125  , -0.145  , -0.405  , -0.965  , -1.415  ,        NACEL036
     D 0.378  ,  0.175  , -0.055  , -0.470  , -0.775  , -1.120  ,        NACEL037
     E 0.403  ,  0.212  , -0.005  , -0.333  , -0.665  , -0.975  /        NACEL038
      DATA AB/                                                           NACEL039
     A 0.413  ,  0.233  ,  0.026  , -0.333  , -0.510  , -0.887  ,        NACEL040
     B 0.417  ,  0.245  ,  0.053  , -0.302  , -0.506  , -0.832  ,        NACEL041
     C 0.419  ,  0.254  ,  0.071  , -0.278  , -0.502  , -0.790  ,        NACEL042
     D 0.420  ,  0.262  ,  0.082  , -0.259  , -0.490  , -0.752  ,        NACEL043
     E 0.421  ,  0.271  ,  0.090  , -0.241  , -0.480  , -0.720  /        NACEL044
      DATA AC/                                                           NACEL045
     A 0.000  , -0.360  , -0.900  , -1.570  , -2.430  , -3.300  ,        NACEL046
     B 0.157  , -0.125  , -0.475  , -1.118  , -1.680  , -2.750  ,        NACEL047
     C 0.260  ,  0.018  , -0.258  , -0.788  , -1.075  , -1.670  ,        NACEL048
     D 0.328  ,  0.102  , -0.130  , -0.583  , -0.930  , -1.250  ,        NACEL049
     E 0.345  ,  0.160  , -0.060  , -0.464  , -0.770  , -1.020  /        NACEL050
      DATA AD/                                                           NACEL051
     A 0.386  ,  0.196  , -0.018  , -0.385  , -0.664  , -0.902  ,        NACEL052
     B 0.398  ,  0.220  ,  0.011  , -0.330  , -0.595  , -0.836  ,        NACEL053
     C 0.407  ,  0.238  ,  0.034  , -0.287  , -0.545  , -0.780  ,        NACEL054
     D 0.414  ,  0.252  ,  0.055  , -0.258  , -0.507  , -0.766  ,        NACEL055
     E 0.417  ,  0.263  ,  0.071  , -0.222  , -0.492  , -0.742  /        NACEL056
      DATA AE/                                                           NACEL057
     A -0.215 , -0.590  , -1.140  , -2.150  , -3.150  , -4.450  ,        NACEL058
     B 0.020  , -0.295  , -0.700  , -1.465  , -2.195  , -3.240  ,        NACEL059
     C 0.160  , -0.105  , -0.408  , -0.980  , -1.450  , -2.000  ,        NACEL060
     D 0.255  ,  0.010  , -0.255  , -0.710  , -1.070  , -1.455  ,        NACEL061
     E 0.310  ,  0.088  , -0.145  , -0.554  , -0.860  , -1.180  /        NACEL062
      DATA AF/                                                           NACEL063
     A 0.345  ,  0.152  , -0.075  , -0.450  , -0.725  , -1.024  ,        NACEL064
     B 0.367  ,  0.200  , -0.030  , -0.383  , -0.643  , -0.930  ,        NACEL065
     C 0.386  ,  0.225  ,  0.012  , -0.328  , -0.590  , -0.880  ,        NACEL066
     D 0.401  ,  0.243  ,  0.048  , -0.280  , -0.541  , -0.850  ,        NACEL067
     E 0.412  ,  0.258  ,  0.060  , -0.245  , -0.509  , -0.820  /        NACEL068
      DATA AG/                                                           NACEL069
     A -0.550 , -0.950  , -1.600  , -2.940  , -3.500  , -5.200  ,        NACEL070
     B -0.250 , -0.570  , -1.020  , -1.900  , -2.650  , -3.920  ,        NACEL071
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C  0.000  , -0.275  , -0.600  , -1.230  , -1.770  , -2.385  ,      NACEL072
D  0.150  , -0.065  , -0.340  , -0.950  , -1.365  , -1.960  ,      NACEL073
E  0.255  ,  0.020  , -0.200  , -0.900  , -1.215  , -1.800  /      NACEL074
 DATA AH/                                                          NACEL075
A  0.315  ,  0.120  , -0.110  , -0.685  , -1.130  , -1.715  ,      NACEL076
B  0.355  ,  0.173  , -0.050  , -0.614  , -1.097  , -1.665  ,      NACEL077
C  0.375  ,  0.195  ,  0.000  , -0.575  , -1.060  , -1.640  ,      NACEL078
D  0.392  ,  0.225  ,  0.032  , -0.545  , -1.035  , -1.625  ,      NACEL079
E  0.405  ,  0.248  ,  0.060  , -0.520  , -1.017  , -1.617  /      NACEL080
 DATA BA/                                                          NACEL081
A -0.485  , -0.460  , -0.450  , -0.410  , -0.400  , -0.385  ,      NACEL082
B -0.335  , -0.330  , -0.315  , -0.300  , -0.295  , -0.280  ,      NACEL083
C -0.240  , -0.239  , -0.230  , -0.225  , -0.220  , -0.215  ,      NACEL084
D -0.175  , -0.185  , -0.170  , -0.170  , -0.165  , -0.164  ,      NACEL085
E -0.140  , -0.145  , -0.135  , -0.140  , -0.135  , -0.135  /      NACEL086
 DATA BB/                                                          NACEL087
A -0.115  , -0.120  , -0.110  , -0.115  , -0.110  , -0.115  ,      NACEL088
B -0.100  , -0.105  , -0.100  , -0.100  , -0.100  , -0.100  ,      NACEL089
C -0.093  , -0.095  , -0.095  , -0.095  , -0.092  , -0.095  ,      NACEL090
D -0.090  , -0.090  , -0.090  , -0.090  , -0.090  , -0.090  ,      NACEL091
E -0.088  , -0.088  , -0.088  , -0.088  , -0.088  , -0.085  /      NACEL092
 DATA BC/                                                          NACEL093
A -0.540  , -0.500  , -0.480  , -0.460  , -0.410  , -0.435  ,      NACEL094
B -0.365  , -0.350  , -0.335  , -0.320  , -0.305  , -0.305  ,      NACEL095
C -0.270  , -0.265  , -0.245  , -0.235  , -0.230  , -0.230  ,      NACEL096
D -0.205  , -0.205  , -0.185  , -0.175  , -0.175  , -0.180  ,      NACEL097
E -0.165  , -0.160  , -0.145  , -0.140  , -0.140  , -0.145  /      NACEL098
 DATA BD/                                                          NACEL099
A -0.140  , -0.130  , -0.120  , -0.115  , -0.115  , -0.120  ,      NACEL100
B -0.125  , -0.110  , -0.105  , -0.100  , -0.100  , -0.105  ,      NACEL101
C -0.115  , -0.095  , -0.095  , -0.095  , -0.092  , -0.095  ,      NACEL102
D -0.110  , -0.090  , -0.090  , -0.090  , -0.090  , -0.090  ,      NACEL103
E -0.105  , -0.085  , -0.085  , -0.085  , -0.088  , -0.085  /      NACEL104
 DATA BE/                                                          NACEL105
A -0.595  , -0.535  , -0.535  , -0.460  , -0.445  , -0.445  ,      NACEL106
B -0.420  , -0.390  , -0.370  , -0.350  , -0.335  , -0.330  ,      NACEL107
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     C -0.330  , -0.310  , -0.275  , -0.260  , -0.260  , -0.260  ,         NACEL108
     D -0.275  , -0.265  , -0.215  , -0.205  , -0.205  , -0.195  ,         NACEL109
     E -0.250  , -0.230  , -0.175  , -0.165  , -0.165  , -0.160  /         NACEL110
      DATA BE/                                                             NACEL111
     A -0.235  , -0.205  , -0.145  , -0.145  , -0.140  , -0.138  ,         NACEL112
     B -0.235  , -0.165  , -0.135  , -0.130  , -0.125  , -0.125  ,         NACEL113
     C -0.240  , -0.170  , -0.125  , -0.120  , -0.118  , -0.118  ,         NACEL114
     D -0.250  , -0.155  , -0.120  , -0.115  , -0.115  , -0.113  ,         NACEL115
     E -0.265  , -0.145  , -0.118  , -0.112  , -0.114  , -0.110  /         NACEL116
      DATA BG/                                                             NACEL117
     A -0.670  , -0.610  , -0.570  , -0.525  , -0.475  , -0.480  ,         NACEL118
     B -0.485  , -0.460  , -0.415  , -0.380  , -0.365  , -0.360  ,         NACEL119
     C -0.375  , -0.373  , -0.335  , -0.293  , -0.285  , -0.290  ,         NACEL120
     D -0.348  , -0.322  , -0.285  , -0.235  , -0.232  , -0.225  ,         NACEL121
     E -0.331  , -0.300  , -0.255  , -0.200  , -0.195  , -0.190  /         NACEL122
      DATA BH/                                                             NACEL123
     A -0.337  , -0.295  , -0.238  , -0.176  , -0.171  , -0.168  ,         NACEL124
     B -0.360  , -0.300  , -0.231  , -0.163  , -0.157  , -0.154  ,         NACEL125
     C -0.400  , -0.310  , -0.230  , -0.157  , -0.150  , -0.145  ,         NACEL126
     D -0.447  , -0.323  , -0.229  , -0.155  , -0.146  , -0.139  ,         NACEL127
     E -0.499  , -0.336  , -0.230  , -0.153  , -0.144  , -0.135  /         NACEL128
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)            NACEL129
C                                                                          NACEL130
C       ZK    IS THE DECIMAL PART OF THE ANNULUS OCCUPIED BY THE           NACEL131
C       AUXILIARY INLET THAT IS ACTUALLY OPENING.  THE REMAINDER IS        NACEL132
C       STRUCTURE.                                                         NACEL133
C                                                                          NACEL134
      ZK=.9                                                                NACEL135
      SPC=(HS+HA)*RHOW*G                                                   NACEL136
      PVP=PV*RHOW*G                                                        NACEL137
      VELR(1)=VI(1)/VO(1)                                                  NACEL138
C                                                                          NACEL139
C       SIGTV  IS THE INCIPIENT CAVITATION NO. ON THE ELBOW TURNING        NACEL140
C       VANES REFERENCED TO DIFFUSER EXIT PRESSURE AND VELOCITY.           NACEL141
C                                                                          NACEL142
      SIGTV=0.4                                                            NACEL143
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```
      JNUMB=2                                                           NACEL144
      IF(ISTPT.EQ.3)JNUMB=NUMB                                          NACEL145
      DO 10 I=ISTPT,JNUMB                                               NACEL146
      QO(I)=.5*RHOW*VO(I)*VO(I)                                         NACEL147
C                                                                       NACEL148
C      SIGI(I) IS THE INCIPIENT CAVITATION NO. REFERENCED TO FREE STREAMNACEL149
C      CONDITIONS.                                                      NACEL150
C                                                                       NACEL151
      SIGI(I)=(SPO-PVP)/QO(I)                                           NACEL152
      PTO(I)=SPO+QO(I)                                                  NACEL153
   10 CONTINUE                                                          NACEL154
      IF(TRIM(1).GT.3.)TRIM(1)=3.                                       NACEL155
      CPEX=-SIGI(1)                                                     NACEL156
C                                                                       NACEL157
C      INTERPOLATE IN THE DATA TABLE TO FIND THE INLET WITH THE DESIRED NACEL158
C      PRESSURE COEFFICIENT.                                            NACEL159
C                                                                       NACEL160
      DO 610 I=1,2                                                      NACEL161
      DO 609 K=1,10                                                     NACEL162
      DO 608 J=1,6                                                      NACEL163
      CDUMX(J)=CPEXT(J,K,I)                                             NACEL164
  608 CONTINUE                                                          NACEL165
      CDUMY(K)=TABLE(VPT,CDUMX,VELR(1),NL)                              NACEL166
  609 CONTINUE                                                          NACEL167
      XDTT(I)=TABLE(CDUMY,XCT,CPEX,KL)                                  NACEL168
  610 CONTINUE                                                          NACEL169
      ML(1)=2                                                           NACEL170
      XD=TABLE(AT,XDTT,TRIM(1),ML)                                      NACEL171
      DIDMX=TABLE(XDT,DIDMT,XD,KL)                                      NACEL172
      WGTS(1,1)=1.E10                                                   NACEL173
C                                                                       NACEL174
C      IF THE TRIAL NACELLE HAS LESS FRONTAL AREA THAN THE MINIMUM      NACEL175
C      REQUIRED TO AVOID CAVITATION, REJECT THE TRIAL VALUE.  IF NON-   NACEL176
C      CAVITATING, CALCULATE INLET DIMENSIONS.                          NACEL177
C                                                                       NACEL178
      IF(DIDMX.LT.DIDM*(1.+DELTA).AND.DELTA.GT.1.E-2) RETURN            NACEL179
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```
      QI=.5*Q(1)                                                        NACEL180
      AI=QI/VI(1)                                                       NACEL181
      DI=SQRT(AI)*1.12838                                               NACEL182
   11 CONTINUE                                                          NACEL183
      DM=DI/DIDM                                                        NACEL184
      XD=TABLE(DIDMT,XDT,DIDM,KL)                                       NACEL185
      FLOXT=DM*XD                                                       NACEL186
C     ASSUMING THE AUX. INLETS ALLOW FLOW TO ENTER BEFORE THE DIFFUSER, NACEL187
C     CALCULATE LOSSES AND TOTAL PRESSURE OF THE COMBINED FLOW.         NACEL188
      CPIN=-SIGI(2)                                                     NACEL189
C                                                                       NACEL190
C      INTERPOLATE IN THE DATA TABLE TO DETERMINE THE MAXIMIM VELOCITY  NACEL191
C      RATIOS AT CRUISE AND TAKE-OFF.                                   NACEL192
C                                                                       NACEL193
      DO 710 I=1,4                                                      NACEL194
      DO 709 K=1,6                                                      NACEL195
      DO 708 J=1,10                                                     NACEL196
      CDUMX(J)=CPINT(K,J,I)                                             NACEL197
  708 CONTINUE                                                          NACEL198
      CDUMY(K)=TABLE(XDT,CDUMX,XD,KL)                                   NACEL199
  709 CONTINUE                                                          NACEL200
      VRTT(I)=TABLE(CDUMY,VRT,CPIN,IL)                                  NACEL201
      VRTEX(I)=TABLE(CDUMY,VRT,CPEX,IL)                                 NACEL202
  710 CONTINUE                                                          NACEL203
      ML(1)=4                                                           NACEL204
      VRMAX(1)=TABLE(ALFAT,VRTEX,TRIM(1),ML)                            NACEL205
      VRMAX(2)=TABLE(ALFAT,VRTT,TRIM(2),ML)                             NACEL206
C                                                                       NACEL207
C     CHECK FOR LIP CAVITATION. IF CAVITATING, RETURN                   NACEL208
C                                                                       NACEL209
      IF(VELR(1).GT.VRMAX(1).AND.DELTA.GT.1.E-3) RETURN                 NACEL210
C                                                                       NACEL211
C      DETERMINE MAX. FLOW RATE AT TAKE-OFF AND COMPARE WITH REQUIRED   NACEL212
C      FLOW RATE.  AN AUXILIARY INLET MUST BE SIZED TO ACCEPT ANY EXCESSNACEL213
C      REQUIRED FLOW.                                                   NACEL214
C                                                                       NACEL215
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      QIN=AI*VRMAX(2)*V0(2)                                             NACEL216
      QC=0.5*Q(2)                                                       NACEL217
      QAUX=QC-QIN                                                       NACEL218
      IF(QAUX.LE.0.)QAUX=0.                                             NACEL219
      QIN=QC-QAUX                                                       NACEL220
      KDEX=0                                                            NACEL221
C     CALCULATE STATIC PRESSURE IMMEDIATELY AFT. OF THE LIP.            NACEL222
      VI2=QIN/AI                                                        NACEL223
      VR=VI2/V0(2)                                                      NACEL224
      PRL2=TABLE(VRT,PRLT,VR,JL)                                        NACEL225
      PTI=PRL2*Q0(2)+SP0                                                NACEL226
      SPI=PTI-0.5*RHOW*VI2*VI2                                          NACEL227
C     CALCULATE COMBINED FLOW PRESSURES AND AUX. INLET AREA.            NACEL228
      AIAUX=0.                                                          NACEL229
      VIAUX=0.                                                          NACEL230
      PTAUX=0.                                                          NACEL231
      IF(QAUX.EQ.0.)GO TO 12                                            NACEL232
      PRAUX=0.80                                                        NACEL233
      PTAUX=PRAUX*Q0(2)+SP0                                             NACEL234
      DYP=PTAUX-SPI                                                     NACEL235
      VIAUX=SQRT(2.*DYP/RHOW)                                           NACEL236
      AIAUX=QAUX/VIAUX                                                  NACEL237
   12 CONTINUE                                                          NACEL238
C                                                                       NACEL239
C      THE TOTAL PRESSURE OF THE COMBINED FLOW IS CALCULATED AS THE     NACEL240
C      MASS WEIGHTED AVERAGE OF THE COMBINING FLOWS.                    NACEL241
C                                                                       NACEL242
      PC=(PTI*QIN+PTAUX*QAUX)/QC                                        NACEL243
      VI(2)=SQRT(2.*(PC-SPI)/RHOW)                                      NACEL244
      CLIP(2)=1.-(PC-SP0)/Q0(2)                                         NACEL245
      QDIF=QC                                                           NACEL246
C                                                                       NACEL247
C      CALCULATE THE INTERNAL LENGTHS TO THE DIFFUSER ENTRY.            NACEL248
C                                                                       NACEL249
      ELENT=ELEXT/2.                                                    NACEL250
      PHI=ATAN(.5*(DM-DI)/ELEXT)                                        NACEL251
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      PHS=SIN(PHI)                                                      NACEL252
      X=.5*(SQRT(DI**2+1.27324*ATAUX*PHS/ZK)-DI)/PHS                    NACEL253
      ELAUX=X/COS(PHI)                                                  NACEL254
C     SIZE THE DIFFUSER                                                 NACEL255
      D2=0.9*DM                                                         NACEL256
      D1=DI                                                             NACEL257
      IF(D2.LT.D1)D2=D1                                                 NACEL258
      ELMAX=9.22339*(D2-D1)                                             NACEL259
      ELMIN=2.836075*(D2-D1)                                            NACEL260
C     DECIDE WHICH CONDITION GOVERNS THE DIFFUSER.                      NACEL261
      IF(DI.GT.DC)GO TO 13                                              NACEL262
      II=2                                                              NACEL263
      GO TO 14                                                          NACEL264
   13 CONTINUE                                                          NACEL265
      II=1                                                              NACEL266
      ODIF=DI                                                           NACEL267
   14 CONTINUE                                                          NACEL268
      EL=0.5*(ELMAX+ELMIN)                                              NACEL269
      DEL=0.                                                            NACEL270
  111 EL=EL+DEL                                                         NACEL271
      KDEX=KDEX+1                                                       NACEL272
      IF(KDEX.GT.10)GO TO 112                                           NACEL273
      ELD=ELENT+EL+3.54491*D2+ELAUX                                     NACEL274
      ELL=5.5*DM                                                        NACEL275
      ELN=ELD                                                           NACEL276
      IF(ELL.GE.ELD)ELN=ELL                                             NACEL277
      ELFAC=(ELD-ELL)                                                   NACEL278
      DDM=0.5*(D2+D1)                                                   NACEL279
      XKT=(1.-(D1/D2)**2)**2                                            NACEL280
      IF(ELFAC.LE.0.)ELFAC=0.                                           NACEL281
      REL=VO(II)*ELN/GNU                                                NACEL282
      RED=VI(II)*D1/GNU                                                 NACEL283
      DL=DM/ELN                                                         NACEL284
      CDRG =CFS(REL)*(1.+1.5*DL**(3/2)+7.*DL**3)                        NACEL285
      ANGL=0.                                                           NACEL286
      IF(EL.LT.0.001)GO TO 109                                          NACEL287
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      ANGL=ATAN((D2-D1)/(2.*EL    ))*57.2958                          NACEL288
  109 CDIF=3.19E-3*ANGL*ANGL+3.452E-4*ANGL                            NACEL289
      POW=CDEG*DM*.5*PI*RHOW*VO(II)**3*ELFAC+(CDIF*XKT+FRICT(RED)*EL/DDMNACEL290
     1)*.5*RHOW*VI(II)*VI(II)*QDIF                                    NACEL291
      DEL=.1*(FLMAX-FLMIN)                                            NACEL292
      IF(KDEX.EQ.1)GO TO 110                                          NACEL293
      DEL=(POWI-POW)*EL/POWI                                          NACEL294
  110 POWI=POW                                                        NACEL295
      IF(DEL.LE.0.01*EL)GO TO 112                                     NACEL296
      GO TO 111                                                       NACEL297
C                                                                     NACEL298
C      ELDIF  IS THE DIFFUSER LENGTH REQUIRING THE LEAST TOTAL POWER  NACEL299
C      FOR THE DESIRED  DIFFUSION RATIO.                              NACEL300
C                                                                     NACEL301
  112 ELDIF=EL                                                        NACEL302
C                                                                     NACEL303
C      CALCULATE THE LIP LOSSES FOR EACH SITUATION.                   NACEL304
C                                                                     NACEL305
      DLIP(1)=1.-TABLE(VPT,PRLT,VELR(1),JL)                           NACEL306
      IF(NUMB.LT.3)GO TO 113                                          NACEL307
      DO 15 J=3,NUMB                                                  NACEL308
      VI(J)=.5*Q(J)/AI                                                NACEL309
      VELR(J)=VI(J)/VO(J)                                             NACEL310
      DLIP(J)=1.-TABLE(VPT,PRLT,VELR(J),JL)                           NACEL311
   15 CONTINUE                                                        NACEL312
  113 JNUMB=2                                                         NACEL313
      IF(ISTRT.EQ.3)JNUMB=NUMB                                        NACEL314
      DO 17 I=ISTRT,JNUMB                                             NACEL315
      CAV(I)=0.                                                       NACEL316
C                                                                     NACEL317
C      CALCULATE THE DIFFUSER AND PIPE LOSSES FOR EACH SITUATION AND  NACEL318
C      ADD TO THE LIP LOSSES.                                         NACEL319
C                                                                     NACEL320
      REND=D1*VI(I)/GNU                                               NACEL321
      DDIF=(CDIF*XKT+FRICT(REND)*ELDIF/DDM)*0.5*RHOW*VI(I)*VI(I)      NACEL322
      PLOSS=DLIP(I)*QO(I)+DDIF+FRICT(REND)*ELAUX/DI*.5*RHOW*VI(1)*VI(1) NACEL323
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      IF(I.EQ.2) PLOSS=DLIP(2)*QO(2)+DDIF                               NACEL324
      VACUT=Q(I)*0.63662/(D2*D2)                                        NACEL325
      SQUAR=SIGI(I)+1.-PLOSS/QO(I)                                      NACEL326
C                                                                       NACEL327
C      DETERMINE THE CRITICAL LOCAL VELOCITY AT THE DIFFUSER EXIT AT    NACEL328
C      WHICH CAVITATION ON THE TURNING VANES OCCURS.                    NACEL329
C                                                                       NACEL330
      VCRIT=SQRT(SQUAR)*VO(I)/SQRT(1.+SIGTV)                            NACEL331
C                                                                       NACEL332
C      ESTIMATE THE MAXIMUM LOCAL VELOCITY AT THE DIFFUSER EXIT.        NACEL333
C                                                                       NACEL334
      VMAX=1.50*VACUT                                                   NACEL335
C                                                                       NACEL336
C      IF CAVITATION OCCURS, REJECT ON DESIGN, INDICATE ON EVALUATION.  NACEL337
C                                                                       NACEL338
      IF(VMAX.GT.VCRIT.AND.ISTRT.EQ.1.AND.DELTA.GT.1.E-9) RETURN        NACEL339
      IF(VMAX.GT.VCRIT)CAV(I)=1.                                        NACEL340
C                                                                       NACEL341
C     AT THIS POINT THE DIFFUSER HAS BEEN SIZED TO AVOID CAVITATION AT  NACEL342
C      BOTH TAKE/OFF AND CRUISE. INTERNAL FLOW LOSSES ARE DETERMINED    NACEL343
C                                                                       NACEL344
      DELH(I,1)=PLOSS/(RHOW*G)                                          NACEL345
      RENL=FLN*VO(I)/GNU                                                NACEL346
C                                                                       NACEL347
C      CALCULATE THE DRAG COEFFICIENTS.                                 NACEL348
C                                                                       NACEL349
      CD(I)=CFS(RENL)*(1.+1.5*(DM/FLN)**(3/2)+7.*(DM/FLN)**3)           NACEL350
C                                                                       NACEL351
C     CALCULATE WETTED SURFACE AND DRAG.                                NACEL352
C                                                                       NACEL353
      FM=SQRT(1.+4.*((2.*FLEXT)/DM)**2)                                 NACEL354
      AFXN=1.0472*DM*DM*(FM+1./(FM+1.))+PI*DM*(FLN-2.*FLEXT)            NACEL355
      CPOD(I)=2.*QO(I)*AFXN*CD(I)                                       NACEL356
   17 CONTINUE                                                          NACEL357
      AREA(1)=PI*D2*D2*0.5                                              NACEL358
      CGS(1,1)=HS+HF-HCL                                                NACEL359
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      CGS(2,1)=XLS+.5*(ELN-3.54421*D2)                               NACEL360
      IF(THATA(1).GE.90.)GO TO 18                                    NACEL361
      CGS(2,1)=CGS(2,1)+CGS(1,1)/TAN(THATA(1)*.0174533)              NACEL362
   18 CGS(3,1)=0.                                                    NACEL363
      CGS(4,1)=0.                                                    NACEL364
      WGTS(1,1)=.11*DM*AEXN*(.5*RHOD-RHOW)+15.07*AREA(1)*(ELENT+ELAUX+  NACEL365
     A EL)                                                           NACEL366
      RETURN                                                         NACEL367
      END                                                            NACEL368
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      SUBROUTINE ELBOW                                                  ELBOW000
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   ELBOW001
      COMMON /SHIP/ DISP,RANGE,BEAM,HS,HF,HCL,XLS,XLPF,XLP              ELBOW002
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           ELBOW003
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           ELBOW004
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   ELBOW005
      COMMON /CONST/PI,G,RHCD                                           ELBOW006
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT  ELBOW007
      COMMON /ITABL/L(2)                                                ELBOW008
C                                                                       ELBOW009
C     ELBOW PERFORMANCE AND DESIGN                                      ELBOW010
C                                                                       ELBOW011
C     REQUIRED INPUT                                                    ELBOW012
C        WIDTH - WIDTH OF DUCT AT ELBOW INLET                           ELBOW013
C        DEPTH - HEIGHT OF DUCT AT ELBOW INLET                          ELBOW014
C        XK    - RADIUS RATIO, RATIO OF THE RADIUS OF THE CENTERLINE OF ELBOW015
C                BEND TO THE INTERNAL RADIUS OF THE DUCT                ELBOW016
C        Q     - FLOW RATE, IN CUBIC FEET PER SECOND                    ELBOW017
C        AREA  - CROSS SECTIONAL AREA OF DUCT AT THE ELBOW, PRESUMED    ELBOW018
C                SAME AT THE INLET AND THE OUTLET                       ELBOW019
C        THATA - ANGLE OF BEND, FROM HORIZONTAL TO OUTSIDE EDGE         ELBOW020
C        GNU   - VISCOSITY OF STANDARD (35 PER CENT SALINITY) SALT WATERELBOW021
C        PI    - 3.14159265                                             ELBOW022
C        ICOMP - INDEX INDICATING WHICH COMPONENT IS BEING LOOKED AT    ELBOW023
C        ISTRT - INDEX NOTING WHICH MODE OF OPERATION FOR THE HYDROFOIL ELBOW024
C        NUMB  - INDEX NOTING HOW MANY MODES TO BE CONSIDERED DURING    ELBOW025
C                THIS PASS                                              ELBOW026
C                                                                       ELBOW027
      DIMENSION SHAPE(3,4),THETA(11),XLOSS(11),ROA(10)                  ELBOW028
      DATA SHAPE/4H ELL,4HIPSE,4H    ,4H CIR,4HCLE ,4H    ,4H REC,      ELBOW029
     A 4HTANG,4HLE  ,4H SQU,4HARE ,4H    /                              ELBOW030
      DATA THETA/0.,10.,20.,30.,40.,50.,60.,70.,80.,90.,95./            ELBOW031
      DATA XLOSS/0.,0.029,0.059,0.08,0.107,0.133,0.156,0.176,0.19,0.198,ELBOW032
     A0.198/                                                            ELBOW033
      FRICT(RE)=(.94259*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)         ELBOW034
      CORR(RE)=1.00057-.16892*ALOG(RE*1.E-5)+.0145885*ALOG(RE*1.E-5)**2 ELBOW035
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     1 -.14948E-2*ALOG(RE*1.E-5)**3                                   ELBOW036
      REMAX=4.E+5                                                      ELBOW037
      KOUNT=ISTRT                                                      ELBOW038
      IELP=ICOMP-ICOMP/2                                               ELBOW039
      AREA(ICOMP)=AREA(ICOMP-1)                                        ELBOW040
      AREA1=.5*AREA(ICOMP)                                             ELBOW041
      IF(IELB.EQ.4) AREA1=.5*AREA1                                     ELBOW042
C                                                                      ELBOW043
C     DETERMINE SHAPE                                                  ELBOW044
C                                                                      ELBOW045
      IJ=0                                                             ELBOW046
      IK=1                                                             ELBOW047
      IF(WIDTH.EQ.DEPTH) IJ=1                                          ELBOW048
      IF(ABS(WIDTH*DEPTH-AREA1).LT..05*AREA1) IK=3                     ELBOW049
      ITYPE=IJ+IK                                                      ELBOW050
C                                                                      ELBOW051
C        ITYPE      SHAPE                                              ELBOW052
C                                                                      ELBOW053
C          1        ELLIPSE                                            ELBOW054
C          2        CIRCLE                                             ELBOW055
C          3        RECTANGLE                                          ELBOW056
C          4        SQUARE                                             ELBOW057
C                                                                      ELBOW058
      FACTR=(.00229+.041452*XK(IELB)**(-1.96))*XK(IELB)**.84           ELBOW059
C                                                                      ELBOW060
C     DETERMINE EQUIVALENT RADII                                       ELBOW061
C                                                                      ELBOW062
      R0(IELB)=.5*DEPTH                                                ELBOW063
      IF(ITYPE.EQ.1) R0(IELB)=WIDTH*DEPTH*SQRT(2./(WIDTH**2+DEPTH**2)) ELBOW064
C                                                                      ELBOW065
C     TRANSFER SHAPE TO CALLING PROGRAM                                ELBOW066
C                                                                      ELBOW067
      DO 1 N=1,3                                                       ELBOW068
    1 TYPE(N,IELP)=SHAPE(N,ITYPE)                                      ELBOW069
C                                                                      ELBOW070
C     FIND BEND RADII                                                  ELBOW071
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C                                                                       ELBOW072
      RIN=RO(IELB)*(XK(IELB)-1.)                                        ELBOW073
      ROUT=RIN+2.*RO(IELB)                                              ELBOW074
C                                                                       ELBOW075
C     IF XK=R/RO IS LE. 1. DO NOT USE SPLITTERS METHOD....              ELBOW076
C     USE THIN TURNING VANES CALCULATION                                ELBOW077
C                                                                       ELBOW078
      IF(XK(IELB).LE.1.) GO TO 100                                      ELBOW079
C                                                                       ELBOW080
C     DETERMINE NUMBER OF VANES REQUIRED FOR MINIMUM LOSS               ELBOW081
C     RATIO IS THE OPTIMUM RATIO OF THE INBOARD AND OUTBOARD RADII FOR  ELBOW082
C     MINIMUM LOSS IN THE BEND                                          ELBOW083
C                                                                       ELBOW084
      RATIO=4.3                                                         ELBOW085
      XN=ALOG((XK(IELB)-1.)/(XK(IELB)+1.))/ALOG((RATIO-1.)/(RATIO+1.))  ELBOW086
      N=XN+.5                                                           ELBOW087
      IF(N.EQ.0) N=1                                                    ELBOW088
      N1=N-1                                                            ELBOW089
      IF(N1.LE.0) N1=1                                                  ELBOW090
C                                                                       ELBOW091
C     FIND THE RATIO OF THE INSIDE RADIUS TO OUTSIDE RADIUS OF ANY OF THELBOW092
C     SUBDIVIDED ELBOWS                                                 ELBOW093
C                                                                       ELBOW094
      RATIO=(RIN/ROUT)**(1./FLOAT(N))                                   ELBOW095
C                                                                       ELBOW096
C     N = NUMBER OF SUBDIVIDED ELBOWS                                   ELBOW097
C     N1 = NUMBER OF SPLITTERS                                          ELBOW098
C                                                                       ELBOW099
C     COMPUTE HEAD LOSSES FOR EACH SUBDIVIDED ELBOW, STARTING FROM INSIDELBOW100
C     NOTE THE MAXIMUM REYNOLDS NUMBER THE EQUATION IS GOOD FOR, AND    ELBOW101
C     CORRECT FOR THE ACTUAL REYNOLDS NUMBER IF ABOVE THE MAXIMUM       ELBOW102
C     N.B. THE REYNOLDS NUMBER IS CALCULATED FROM THE SUBDIVIDED ELBOW, ELBOW103
C     NOT THE ORIGINAL ELBOW                                            ELBOW104
C                                                                       ELBOW105
    4 SUM=0.                                                            ELBOW106
      RIA=RIN                                                           ELBOW107
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      V=Q(KOUNT)/AREA(ICOMP)                                           ELBOW108
      DO 3 I=1,N                                                       ELBOW109
      ROA(I)=RIA/RATEO                                                 ELBOW110
      HGT=ROA(I)-RIA                                                   ELBOW111
      AA=PI*HGT*HGT*.25                                                ELBOW112
      IF(ITYPE.EQ.3.OR.ITYPE.EQ.4) AA=WIDTH*HGT                        ELBOW113
      RAD=HGT*PI*.25                                                   ELBOW114
      IF(ITYPE.EQ.3.OR.ITYPE.EQ.4) RAD=.5*(HGT+WIDTH)                  ELBOW115
      RE=AA*V/(RAD*GNU)                                                ELBOW116
      XCORR=1.                                                         ELBOW117
      IF(RE.LT.REMAX) GO TO 7                                          ELBOW118
      XCORR=CORR(RE)/CORR(REMAX)                                       ELBOW119
      RE=REMAX                                                         ELBOW120
    7 XKT=XCORR*FACTR*THATA(IELB)*RE**(-.17)                           ELBOW121
      RIA=ROA(I)                                                       ELBOW122
    3 SUM=SUM+XKT*AA                                                   ELBOW123
      HEAD=SUM/AREA1*.5*V*V/G                                          ELBOW124
      GO TO 5                                                          ELBOW125
C                                                                      ELBOW126
C     THIN,CIRCULAR ARC TURNING VANE CALCULATIONS                      ELBOW127
C                                                                      ELBOW128
  100 XCORR=1.                                                         ELBOW129
      DIAM=2.*RO(IELB)                                                 ELBOW130
      IF(ITYPE.EQ.3.OR.ITYPE.EQ.4) DIAM=2.*WIDTH*DEPTH/(WIDTH**2+DEPTH**ELBOW131
     A 2)                                                              ELBOW132
      RE=DIAM*V/GNU                                                    ELBOW133
      IF(RE.GT.1.E+5) XCORR=CORR(RE)/CORR(1.E+5)                       ELBOW134
      XKT=TABLE(THETA,XLOSS,THATA(IELB),L)                             ELBOW135
      HEAD=(FRICT(RE)*RO(IELB)*XK(IELB)*THATA(IELB)*.0174533/DIAM+XKT) ELBOW136
     A *.5*V*V/G*XCORR                                                 ELBOW137
    5 DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+HEAD                       ELBOW138
      IF(IELB.EQ.2) DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP)+RO(2)*XK(2)    ELBOW139
      IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 4                          ELBOW140
      KOUNT=KOUNT+1                                                    ELBOW141
      IF(XK(IELB).GT.1.) GO TO 6                                       ELBOW142
      V=Q(KOUNT)/AREA(ICOMP)                                           ELBOW143
```

```
      GO TO 100                                                         ELBOW144
C                                                                       ELBOW145
C     ELBOW STRUCTURE WEIGHT CALCULATIONS                               ELBOW146
C                                                                       ELBOW147
    4 VOLV=0.                                                           ELBOW148
      IF(XK(IELB).LE.1.) GO TO 9                                        ELBOW149
      DO 8 I=1,N1                                                       ELBOW150
    8 VOLV=VOLV+8.7267E-4*THATA(IELB)*ROA(I)*RIN*WIDTH                 ELBOW151
    9 VOL=VOLV+THATA(IELB)*RO(IFLB)*XK(IELB)*AREA(ICOMP)/(134.56*RHOD)  ELBOW152
      WGTS(1,ICOMP)=VOL*RHOD*G                                          ELBOW153
      WGTS(2,ICOMP)=AREA(ICOMP)*RHOW*G*THATA(IELB)*RO(IELB)*XK(IELB)*   ELBOW154
     A .0174533                                                         ELBOW155
      RETURN                                                            ELBOW156
      END                                                               ELBOW157
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```
      SUBROUTINE STRUT                                                  STRUT000
C     STRUT DIFFUSER                                                    STRUT001
C                                                                       STRUT002
C     REQUIRED INPUTS                                                   STRUT003
C        HE     - ELEVATION OF PUMP CENTERLINE ABOVE MEAN WATER         STRUT004
C        HS     - DEPTH OF SUBMERGENCE                                  STRUT005
C        RO(1)  - HALF THE HEIGHT OF THE INLET TO THE DIFFUSER          STRUT006
C        RO(2)  - HALF THE HEIGHT OF THE INLET TO THE HULL ELBOW        STRUT007
C        XK1    - RADIUS RATIO OF THE STRUT ELBOW                       STRUT008
C        XK2    - RADIUS RATIO OF THE HULL ELBOW                        STRUT009
C        ITYPE  - 1 OR 3                                                STRUT010
C              ONE - ELLIPSE                                            STRUT011
C              THREE - RECTANGLE                                        STRUT012
C        Q      - FLOW RATE IN CUBIC FEET PER SECOND                    STRUT013
C        PI     - 3.14159265                                            STRUT014
C        AREA   - AREA OF DUCT INLET                                    STRUT015
C                                                                       STRUT016
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED                     STRUT017
C        TABLE - ONE DIMENSIONAL TABLE LOOK UP FUNCTION SUBPROGRAM      STRUT018
C                                                                       STRUT019
      LOGICAL IFUEL,IPUMP                                               STRUT020
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   STRUT021
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           STRUT022
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           STRUT023
      COMMON /STRTC/TC,T,C,T1,C1,CFM                                    STRUT024
      COMMON /CONST/PI,G,RHOD                                           STRUT025
      COMMON /DRAG/TDRAG(5),STRTD(5),PODD(5),SPRAY(5),REST(5),VO(5),    STRUT026
     1 TRIM(5)                                                          STRUT027
      COMMON /CDRAG/CSTRT(5),CPOD(5),CSPRY(5)                           STRUT028
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPF,XLP               STRUT029
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   STRUT030
      COMMON /INDEX/IEVAL,IEOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT  STRUT031
      COMMON /ITABL/L(2)                                                STRUT032
      COMMON IFUEL,IPUMP                                                STRUT033
      DIMENSION THET2(22),EXPAN(22)                                     STRUT034
      DATA THET2/0.,2.,4.,6.,8.,10.,12.,15.,17.5,20.,25.,27.,30.,32.,   STRUT035
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     1 34.,39.,45.,50.,60.,70.,80.,90./                                    STRUT036
      DATA EXPAN/0.,.005,.015,.03,.05,.09,.17,.3,.4,.5,.7,.8,.91,0.97,    STRUT037
     A 1.0,1.03,1.04,1.04,1.037,1.035,1.033,1.03/                           STRUT038
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)            STRUT039
C                                                                          STRUT040
C     FIND EFFECTIVE LENGTH FOR EITHER GENERALIZED RECTANGLE OR ELLIPSE    STRUT041
      WGTS(1,ICOMP)=1.E11                                                  STRUT042
      AREA(ICOMP)=2.*AREA(ICOMP-1)                                         STRUT043
      IF(.NOT.IPUMP) GO TO 5                                               STRUT044
      AREA(ICOMP)=AREA(8)                                                  STRUT045
      IF(AREA(8).LT.AREA(7).AND.AREA(4).GT.AREA(7)) AREA(ICOMP)=AREA(4)    STRUT046
    5 IF(AREA(ICOMP).LT.AREA(ICOMP-1)) AREA(ICOMP)=AREA(ICOMP-1)           STRUT047
      ARATO=AREA(ICOMP)/AREA(ICOMP-1)                                      STRUT048
C                                                                          STRUT049
C     SIZE STRUT EXTERNAL DIMENSIONS                                       STRUT050
C                                                                          STRUT051
      VL=1.137*VO(1)                                                       STRUT052
      SIGMA=(HA*G-PV*G)/(.5*VL*VL)                                         STRUT053
      TC=(SQRT(1.+SIGMA)-1.)/1.15                                          STRUT054
      IF(TC.LT..12) TC=.12                                                 STRUT055
      C=SQRT(AREA(ICOMP)/TC)                                               STRUT056
      T=TC*C                                                               STRUT057
C                                                                          STRUT058
C     T AND C ARE THE THICKNESS AND CHORD AT THE STRUT EXIT                STRUT059
C                                                                          STRUT060
      C1=SQRT(AREA(ICOMP-1)/TC)                                            STRUT061
      T1=TC*C1                                                             STRUT062
C                                                                          STRUT063
C     C1 AND T1 ARE THE CHORD AND THICKNESS AT THE STRUT INLET             STRUT064
C                                                                          STRUT065
      CM=.5*(C+C1)                                                         STRUT066
C                                                                          STRUT067
C     FIND EQUIVALENT DIAMETERS                                            STRUT068
C                                                                          STRUT069
      IF(ITYPE/2.EQ.0) GO TO 1                                             STRUT070
      DEIN=WIDTH*DEPTH/(WIDTH+DEPTH)                                       STRUT071
```

```
      WIDTH=SQRT(AREA(ICOMP))*.5                                        STRUT072
      WIDE =2.*WIDTH                                                    STRUT073
      DEOUT=WIDE*WIDTH/(WIDE+WIDTH)                                     STRUT074
      RO(2)=.5*WIDTH                                                    STRUT075
      GO TO 2                                                           STRUT076
    1 DEIN=WIDTH*DEPTH*SQRT(2./(WIDTH*WIDTH+DEPTH*DEPTH))               STRUT077
      WIDTH=SQRT(AREA(ICOMP)/PI)                                        STRUT078
      WIDE=2.*WIDTH                                                     STRUT079
      DEOUT=WIDTH*WIDE*SQRT(2./(WIDE*WIDE+WIDTH*WIDTH))                 STRUT080
      RO(2)=.5*DEOUT                                                    STRUT081
    2 DEAVE=DEIN+DEOUT                                                  STRUT082
      STRT=HE+HS-RO(1)*XK(1)-RO(2)*XK(2)                                STRUT083
      IF(STRT.LE.0.) RETURN                                             STRUT084
      XLONG=STRT/SIN(THATA(1)*.0174533)                                 STRUT085
C                                                                       STRUT086
C     FIND EQUIVALENT ANGLE OF DIFFUSER, TWO THETA                      STRUT087
C                                                                       STRUT088
      STAN=(WIDE-DEPTH)*.5/XLONG                                        STRUT089
      THETA=2.*ATAN(STAN)*57.29578                                      STRUT090
C                                                                       STRUT091
C     FIND EXPANSION COEFFICIENT                                        STRUT092
C                                                                       STRUT093
      ECOEF=TABLE(THET2,EXPAN,THETA,L)                                  STRUT094
C                                                                       STRUT095
C     FORM THE EXPANSION LOSS COEFFICIENT                               STRUT096
C                                                                       STRUT097
      FORML=ECOEF*(1.-1./ARATO)**2                                      STRUT098
C                                                                       STRUT099
C     DETERMINE INLET AND OUTLET VELOCITIES                             STRUT100
C                                                                       STRUT101
      DEPTH=WIDTH                                                       STRUT102
      WIDTH=WIDE                                                        STRUT103
      KOUNT=ISTRT                                                       STRUT104
    3 VELIN=Q(KOUNT)/AREA(ICOMP-1)                                      STRUT105
      VLOUT=VELIN/ARATO                                                 STRUT106
C                                                                       STRUT107
```

```
C     DETERMINE STRUT DRAG FROM HOERNER                                  STRUT108
C     DETERMINE SPRAY DRAG FROM SHERMAN AND LINCOLN                      STRUT109
C                                                                        STRUT110
      RES=CM*VO(KOUNT)/GNU                                               STRUT111
      CDS=2.*CFS(RES)*(1.+2.*TC+60.*TC**4)                               STRUT112
      CFM=HS/(HS+HF-RO(2)*XK(2))*(C-C1)+C1                               STRUT113
      CSTRT(KOUNT)=CDS*RHOW*VO(KOUNT)**2*HS/SIN(THATA(1)*.0174533)*.5    STRUT114
     A *(CFM+C1)                                                         STRUT115
      CDSP=.03*TC                                                        STRUT116
      CSPRY(KOUNT)=CSTRT(KOUNT)*(CDSP/CDS)                               STRUT117
C                                                                        STRUT118
C     CALCULATE THE STRAIGHT PIPE FRICTION COEFFICIENT                   STRUT119
C                                                                        STRUT120
      RE=VELIN*DEIN/GNU                                                  STRUT121
      PIPEL=FRICT(RE)*XLONG/DEIN                                         STRUT122
C                                                                        STRUT123
C     LOSS COEFFICIENT WHICH IS PROPORTIONAL TO VELOCITY HEAD AT INLET   STRUT124
C                                                                        STRUT125
      TOTAL=FORML+PIPEL                                                  STRUT126
C                                                                        STRUT127
C     HEAD LOSS DUE TO DIFFUSER                                          STRUT128
C                                                                        STRUT129
      HEADL=.5*TOTAL*VELIN*VELIN/G                                       STRUT130
C                                                                        STRUT131
C     TOTAL HEAD LOSS DUE TO DIFFUSER AND ELEVATION                      STRUT132
C                                                                        STRUT133
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+HEADL+HF-RO(2)*XK(2)         STRUT134
      IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 4                            STRUT135
      KOUNT=KOUNT+1                                                      STRUT136
      GO TO 3                                                            STRUT137
C                                                                        STRUT138
C     CENTER OF GRAVITY CALCULATIONS                                     STRUT139
C                                                                        STRUT140
    4 HGT=XLONG-HS+RO(1)*XK(1)                                           STRUT141
      CGWS=HGT*(3.*ARATO+2.*SQRT(ARATO)+1.)*.25/(ARATO+SQRT(ARATO)+1.)   STRUT142
      CGS(3,ICOMP)=-CGWS                                                 STRUT143
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      CGS(4,ICOMP)=XLS+CGWS*COTAN(THATA(1)*.0174533)                    STRUT144
      CGS(1,ICOMP)=CGS(3,ICOMP)                                         STRUT145
      CGS(2,ICOMP)=CGS(4,ICOMP)                                         STRUT146
C                                                                       STRUT147
C     WEIGHT CALCULATIONS                                               STRUT148
C                                                                       STRUT149
      WGTS(1,ICOMP)=.250*(T+T1)*CM*XLONG*RHOW*G                         STRUT150
      WGTS(2,ICOMP)=HGT/3.*AREA(ICOMP)*(ARATO+1.+SQRT(ARATO))*RHOW*G    STRUT151
      RETURN                                                            STRUT152
      END                                                               STRUT153
```

```
      SUBROUTINE JUNCT                                                  JUNCT000
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   JUNCT001
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP               JUNCT002
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           JUNCT003
      COMMON /CONST/PI,G,RHCD                                           JUNCT004
      COMMON /ELBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           JUNCT005
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   JUNCT006
      COMMON /INDEX/IEVAL,IEOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT  JUNCT007
      COMMON /ITABL/L(2)                                                JUNCT008
      DIMENSION BETA(19),ALAMD(19)                                      JUNCT009
      DATA ALAMD/.975,.97,.967,.963,.96,.957,.953,.95,.948,.945,.94,.93,JUNCT010
     A 0.92,0.9,0.85,0.81,0.75,0.69,0.61/                               JUNCT011
      DATA BETA/0.,5.,10.,15.,20.,25.,30.,35.,40.,45.,50.,55.,60.,65.,70JUNCT012
     A.,75.,80.,85.,90./                                                JUNCT013
      DATA ALPHA/0./                                                    JUNCT014
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)         JUNCT015
      AREA(ICOMP)=AREA(ICOMP-1)                                         JUNCT016
C                                                                       JUNCT017
C     ALPHA IS ANGLE THAT ONE BRANCH MAKES WITH END PIPE IN JUNCTION    JUNCT018
      KOUNT=ISTRT                                                       JUNCT019
C                                                                       JUNCT020
C     MIXING LOSS COEFFICIENT OF JUNCTION                               JUNCT021
C                                                                       JUNCT022
      XLAMD=TABLE(BETA,ALAMD,ALPHA,L)                                   JUNCT023
      AMIXL=1.+XLAMD-2.*COS(.024434*ALPHA-.00583*(ALPHA*.0174533)**2)   JUNCT024
      IF(AMIXL.LT.0.) AMIXL=0.                                          JUNCT025
C                                                                       JUNCT026
      XPUMP=NGT+1                                                       JUNCT027
C                                                                       JUNCT028
C     ASSUMES NO LOSS DUE TO CHANGE OF SHAPE TO CIRCULAR                JUNCT029
C                                                                       JUNCT030
      DIAM=1.414*SQRT(AREA(ICOMP)/PI)                                   JUNCT031
      RO(3)=.5*DIAM                                                     JUNCT032
      AJCT=XLS-RO(3)*XK(3)-XLP-XLPE                                     JUNCT033
      IF(AJCT.LT.0.) AJCT=0.                                            JUNCT034
      FLONG=BEAM/XPUMP-RO(3)*(1.+XK(3))-RO(2)*XK(2)+RO(2)               JUNCT035
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```
      DEPTH=DIAM                                                        JUNCT036
      WIDTH=DEPTH                                                       JUNCT037
    2 ICOMP=5                                                           JUNCT038
C                                                                       JUNCT039
C     FIND HEAD LOSS FOR ATHWARTSHIPS LENGTH                            JUNCT040
C                                                                       JUNCT041
      V=Q(KOUNT)/AREA(ICOMP)                                            JUNCT042
      RE=V*DIAM/GNU                                                     JUNCT043
      FRCTL=FRICT(RE)*FLONG/DIAM                                        JUNCT044
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+FRCTL*.5*V*V/G              JUNCT045
      ICOMP=6                                                           JUNCT046
C                                                                       JUNCT047
C     FIND HEAD LOSS IN PUMP ELBOW                                      JUNCT048
C                                                                       JUNCT049
      CALL ELBOW                                                        JUNCT050
      RE=RE*1.414                                                       JUNCT051
C                                                                       JUNCT052
C     FRICTION LOSS COEFFICIENT IN JUNCTION                             JUNCT053
      FRCTJ=.3535*FRICT(RE)*AJCT/DIAM+FRCTL*AJCT/FLONG*.5               JUNCT054
C                                                                       JUNCT055
C     TOTAL JUNCTION LOSS COEFFICIENT                                   JUNCT056
C                                                                       JUNCT057
      AJCTL=AMIXL+FRCTJ                                                 JUNCT058
C                                                                       JUNCT059
C     HEAD LOSS OF JUNCTION                                             JUNCT060
C                                                                       JUNCT061
      ICOMP=7                                                           JUNCT062
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+AJCTL*.5*V*V/G              JUNCT063
      IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 1                           JUNCT064
      KOUNT=KOUNT+1                                                     JUNCT065
      GO TO 2                                                           JUNCT066
    1 AREA(ICOMP)=AREA(ICOMP-1)                                         JUNCT067
C                                                                       JUNCT068
C     CENTER OF GRAVITY AND WEIGHT CALCULATIONS OF COMPONENTS OF PUMP   JUNCT069
C     INLET PIPING.                                                     JUNCT070
C                                                                       JUNCT071
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      CGS(1,6)=HCL                                                     JUNCT072
      CGS(2,6)=XLS                                                     JUNCT073
      CGS(3,6)=HCL                                                     JUNCT074
      CGS(4,6)=XLS                                                     JUNCT075
      WGTS(1,5)=13.7*AREA(5)*FLONG                                     JUNCT076
      WGTS(2,5)=AREA(5)*FLONG*RHOW*G                                   JUNCT077
      CGS(1,5)=HCL                                                     JUNCT078
      CGS(2,5)=XLS                                                     JUNCT079
      CGS(3,5)=HCL                                                     JUNCT080
      CGS(4,5)=XLS                                                     JUNCT081
      WGTS(1,ICOMP)=13.7*AJCT*AREA(ICOMP)                              JUNCT082
      WGTS(2,ICOMP)=AJCT*AREA(ICOMP)*RHOW*G                            JUNCT083
      CGS(1,ICOMP)=HCL                                                 JUNCT084
      CGS(2,ICOMP)=XLS-RO(3)*XK(3)*SIN(THATA(3)*.008757)-.5*AJCT       JUNCT085
      CGS(3,ICOMP)=HCL                                                 JUNCT086
      CGS(4,ICOMP)=CGS(2,ICOMP)                                        JUNCT087
      DEPTH=1.414*DIAM                                                 JUNCT088
      WIDTH=DEPTH                                                      JUNCT089
      RETURN                                                           JUNCT090
      END                                                              JUNCT091
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```
      SUBROUTINE PIPE                                                   PIPE 092
      COMMON /FLBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           PIPE 093
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   PIPE 094
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           PIPE 095
      COMMON /CONST/PI,G,RHCD                                           PIPE 096
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HF,HCL,XLS,XLPF,XLP               PIPE 097
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   PIPE 098
      COMMON /INDEX/IEVAL,IEQPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT  PIPE 099
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)         PIPE 100
      KOUNT=ISTRT                                                       PIPE 101
      AREA(ICOMP)=AREA(ICOMP-1)                                         PIPE 102
      DIAM=1.414*SQRT(AREA(ICOMP)/PI)                                   PIPE 103
      DEPTH=DIAM                                                        PIPE 104
      WIDTH=DEPTH                                                       PIPE 105
      RO(3)=.5*DIAM                                                     PIPE 106
      APIPE=XLS-XLPF-XLP-RO(3)*XK(3)                                    PIPE 107
      IF(APIPE.LT.0.) APIPE=0.                                          PIPE 108
      XPUMP=NGT                                                         PIPE 109
      XLONG=BEAM/(XPUMP+1.)-RO(3)*XK(3)*SIN(THATA(3)*.008727)-RO(2)*    PIPE 110
     A XK(2)+RO(2)                                                      PIPE 111
    2 ICOMP=5                                                           PIPE 112
C                                                                       PIPE 113
C     FIND HEAD LOSS FOR ATHWARTSHIPS LENGTH                            PIPE 114
C                                                                       PIPE 115
      V=Q(KOUNT)/AREA(ICOMP)                                            PIPE 116
      RE=DIAM*V/GNU                                                     PIPE 117
      FRCTL=FRICT(RE)*XLONG/DIAM                                        PIPE 118
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+.5*FRCTL*V*V/G              PIPE 119
      ICOMP=6                                                           PIPE 120
C                                                                       PIPE 121
C     FIND HEAD LOSS IN PUMP ELBOW                                      PIPE 122
C                                                                       PIPE 123
      CALL ELBOW                                                        PIPE 124
C                                                                       PIPE 125
C     LOSS COEFFICIENT                                                  PIPE 126
C                                                                       PIPE 127
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```
      ICOMP=7
      XKT=FRICT(RE)*APIPE/DIAM
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+.5*XKT*V*V/G
      IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 1
      KOUNT=KOUNT+1
      GO TO 2
    1 AREA(ICOMP)=AREA(ICOMP-1)
C
C     CENTER OF GRAVITY AND WEIGHT CALCULATIONS OF COMPONENTS OF PUMP
C     INLET PIPING
C
      WGTS(1,5)=13.7*XLONG*AREA(5)
      WGTS(2,5)=AREA(5)*XLONG*RHOW*G
      CGS(1,5)=HCL
      CGS(2,5)=XLS
      CGS(3,5)=HCL
      CGS(4,5)=XLS
      CGS(1,6)=HCL
      CGS(2,6)=XLS
      CGS(3,6)=HCL
      CGS(4,6)=XLS
      WGTS(1,ICOMP)=13.7*APIPE*AREA(ICOMP)
      WGTS(2,ICOMP)=AREA(ICOMP)*APIPE*RHOW*G
      CGS(1,ICOMP)=HCL
      CGS(2,ICOMP)=XLS-RO(3)*XK(3)*SIN(THATA(3)*.008727)-.5*APIPE
      CGS(3,ICOMP)=HCL
      CGS(4,ICOMP)=CGS(2,ICOMP)
      RETURN
      END
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```
      SUBROUTINE DIVRG                                                  DIVRG000
      LOGICAL IFUEL, IPUMP                                              DIVRG001
      COMMON /H2O/TEMP,PV,RHOW,GNJ,HA                                   DIVRG002
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HF,HCL,XLS,XLPE,XLP               DIVRG003
      COMMON /CONST/PI,G,RHOD                                           DIVRG004
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           DIVRG005
      COMMON /FLBW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           DIVRG006
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   DIVRG007
      COMMON /INDEX/IEVAL,IEOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT  DIVRG008
      COMMON /ITABL/I(2)                                                DIVRG009
      COMMON IFUEL,IPUMP                                                DIVRG010
      DIMENSION THETA(12),COEF(12)                                      DIVRG011
      DATA THETA/0.,10.,20.,30.,40.,50.,60.,70.,80.,90.,100.,110./      DIVRG012
      DATA COEF/0.005,0.04,0.18,0.36,0.57,0.77,0.955,1.14,1.3,1.42,1.5, DIVRG013
     1 1.57/                                                            DIVRG014
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)         DIVRG015
      KOUNT=ISTRT                                                       DIVRG016
      AREA(ICOMP)=AREA(ICOMP-1)                                         DIVRG017
      DIAM=1.414*SQRT(AREA(ICOMP)/PI)                                   DIVRG018
      RO(3)=.5*DIAM                                                     DIVRG019
      XPUMP=NGT+1                                                       DIVRG020
      FLONG=1.5*BEAM/XPUMP-RO(2)*XK(2)+RO(2)-RO(3)*XK(3)*SIN(THATA(3)   DIVRG021
     A *.008727)                                                        DIVRG022
C                                                                       DIVRG023
C     CENTER OF GRAVITY AND WEIGHT CALCULATIONS FOR ATHWARTSHIPS LENGTH DIVRG024
C                                                                       DIVRG025
      WGTS(1,ICOMP)=13.7*FLONG*AREA(ICOMP)                              DIVRG026
      WGTS(2,ICOMP)=AREA(ICOMP)*FLONG*RHOW*G                            DIVRG027
      CGS(1,ICOMP)=HCL                                                  DIVRG028
      CGS(2,ICOMP)=XLS                                                  DIVRG029
      CGS(3,ICOMP)=HCL                                                  DIVRG030
      CGS(4,ICOMP)=XLS                                                  DIVRG031
      RO(4)=.3535*DIAM                                                  DIVRG032
    3 ICOMP=5                                                           DIVRG033
C                                                                       DIVRG034
C     GET FRICTION LOSS FOR FIRST LENGTH                                DIVRG035
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C                                                              DIVRG036
      V=Q(KOUNT)/AREA(ICOMP)                                   DIVRG037
      RE=DIAM*V/GNU                                            DIVRG038
      FRCTL=FRICT(RE)*FLONG/DIAM                               DIVRG039
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+FRCTL*.5*V*V/G     DIVRG040
      WIDTH=DIAM                                               DIVRG041
      DEPTH=WIDTH                                              DIVRG042
C                                                              DIVRG043
C     FIND HEAD LOSS  IN PUMP ELBOW                            DIVRG044
C                                                              DIVRG045
      ICOMP=6                                                  DIVRG046
      CALL ELBOW                                               DIVRG047
      ICOMP=7                                                  DIVRG048
      IF(KOUNT.NE.1) GO TO 7                                   DIVRG049
      THATA(4)=ATAN(BEAM*.5/(XPUMP*(XLS-XLPE-XLP-RO(3)*XK(3))))  DIVRG050
      ANGLE=THATA(4)                                           DIVRG051
      XLONG=XLS-XLPE-XLP-RO(3)*XK(3)-RO(4)*XK(4)               DIVRG052
      IF(XLONG.GT.0.) GO TO 2                                  DIVRG053
      XLONG=0.                                                 DIVRG054
      THATA(4)=0.                                              DIVRG055
      WGTS(1,ICOMP)=0.                                         DIVRG056
      ADIV=0.                                                  DIVRG057
      WGTS(2,ICOMP)=0.                                         DIVRG058
      DIVL=0.                                                  DIVRG059
      ANGLE=0.                                                 DIVRG060
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)                    DIVRG061
      GO TO 6                                                  DIVRG062
    2 ADIV=XLONG/COS(ANGLE)                                    DIVRG063
      THATA(4)=THATA(4)*57.29578                               DIVRG064
      IF(THATA(4).GT.90.) GO TO 5                              DIVRG065
      DIVL=TABLE(THETA,COEF,THATA(4),L)                        DIVRG066
    7 FRCTL=FRICT(RE*.707)*ADIV/DIAM*1.414                     DIVRG067
      DIVLC=DIVL+FRCTL                                         DIVRG068
      HEADL=DIVLC*V*V*.5/G                                     DIVRG069
      WIDTH=.707*WIDTH                                         DIVRG070
      DEPTH=WIDTH                                              DIVRG071
```

```
      IF(KOUNT.EQ.2) ISTRT=2                                            DIVRG072
C                                                                       DIVRG073
C     ELBOW JUST PRIOR TO PUMP INLET                                    DIVRG074
C                                                                       DIVRG075
      CALL ELBOW                                                        DIVRG076
      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP)+HEADL                         DIVRG077
    6 IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 4                           DIVRG078
      KOUNT=KOUNT+1                                                     DIVRG079
      GO TO 3                                                           DIVRG080
    4 CGS(1,6)=HCL                                                      DIVRG081
      IF(KOUNT.EQ.2) ISTRT=1                                            DIVRG082
C                                                                       DIVRG083
C     CENTER OF GRAVITY AND WEIGHT CALCULATIONS OF PUMP ELBOW AND       DIVRG084
C     TRANSITION PIECE(DIVERGENCE)                                      DIVRG085
C                                                                       DIVRG086
      CGS(2,6)=XLS                                                      DIVRG087
      CGS(3,6)=HCL                                                      DIVRG088
      CGS(4,6)=XLS                                                      DIVRG089
      CGS(1,ICOMP)=HCL                                                  DIVRG090
      CGS(3,ICOMP)=HCL                                                  DIVRG091
      DWGT1=WGTS(1,ICOMP)                                               DIVRG092
      DWGT2=13.7*XLONG*AREA(ICOMP)                                      DIVRG093
      DWGT3=DWGT1                                                       DIVRG094
      WWGT1=WGTS(2,ICOMP)                                               DIVRG095
      WWGT2=XLONG*AREA(ICOMP)*.5*RHOW*G                                 DIVRG096
      WWGT3=WWGT1                                                       DIVRG097
      IF(ANGLE.EQ.0.) RETURN                                            DIVRG098
      CGWX1=XLS-RO(3)*XK(3)-SIN(.5*ANGLE)*RO(4)*XK(4)                   DIVRG099
      CGWX2=XLS-RO(3)*XK(3)-.5*XLONG*SIN(ANGLE)-RO(4)*XK(4)*SIN(ANGLE)  DIVRG100
      CGWX3=XLP+XLPE+SIN(.5*ANGLE)*RO(4)*XK(4)                          DIVRG101
      CGS(2,ICOMP)=(DWGT1*CGWX1+DWGT2*CGWX2+DWGT3*CGWX3)/(DWGT1+DWGT2+DWDIVRG102
     1GT3)                                                              DIVRG103
      CGS(4,ICOMP)=(WWGT1*CGWX1+WWGT2*CGWX2+WWGT3*CGWX3)/(WWGT1+WWGT2+  DIVRG104
     1 WWGT3)                                                           DIVRG105
      WGTS(1,ICOMP)=DWGT1+DWGT2+DWGT3                                   DIVRG106
      WGTS(2,ICOMP)=WWGT1+WWGT2+WWGT3                                   DIVRG107
```

```
      RETURN                                                            DIVRG108
      END                                                               DIVRG109
```

```
      SUBROUTINE NOZZL                                                   NOZZL000
      LOGICAL IFUEL,IPUMP                                                NOZZL001
      COMMON /DRAG/TDRAG(5),STRTD(5),PDD(5),SPRAY(5),REST(5),VO(5),      NOZZL002
     1 TRIM(5)                                                           NOZZL003
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                    NOZZL004
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ            NOZZL005
      COMMON /CONST/PI,G,RHOD                                            NOZZL006
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HF,HCL,XLS,XLPF,XLP                NOZZL007
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                    NOZZL008
      COMMON /INDEX/IEVAL,IFOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT   NOZZL009
      COMMON IFUEL,IPUMP                                                 NOZZL010
      DIMENSION QQ(5)                                                    NOZZL011
      FRICT(RE)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)          NOZZL012
      KOUNT=ISTRT                                                        NOZZL013
      XLPS=XLPE                                                          NOZZL014
      XFAC=1.4*HCL/XLPF                                                  NOZZL015
      XPUMP=NPUMP                                                        NOZZL016
      IF(.NOT.IPUMP) AREA(8)=AREA(7)                                     NOZZL017
      AREA(ICOMP)=AJET                                                   NOZZL018
      ANOZ=ATAN(TDRAG(1)/DISP)                                           NOZZL019
C                                                                        NOZZL020
C     XFAC.LT.1. INDICATES NOZZLE EXITS THROUGH BOTTOM                   NOZZL021
C                                                                        NOZZL022
      IF(XFAC.LT.1.) XLPS=1.4*HCL                                        NOZZL023
      XLNOZ=XLPS/COS(ANOZ)                                               NOZZL024
      DT=2.*SQRT(AREA(ICOMP-1)/(PI*XPUMP))                               NOZZL025
      DJ=2.*SQRT(AJET/(PI*XPUMP))                                        NOZZL026
      IF(DT.LT.DJ) GO TO 3                                               NOZZL027
    1 QQ(KOUNT)=Q(KOUNT)/XPUMP                                           NOZZL028
      XCORR=XLNOZ/(DT-DJ)*(1.-(2./(1.+DT/DJ))**4)*VJ(KOUNT)*VJ(KOUNT)/G*NOZZL029
     1.25                                                                NOZZL030
      RE=8.*QQ(KOUNT)/(PI*(DT+DJ)*GNU)                                   NOZZL031
      IF(DJ.LT.1.) XCORR=.0075*VJ(KOUNT)**2/(G*FRICT(RE))                NOZZL032
      IF(ABS(DT-DJ).LT..01) XCORR=XLNOZ/(G*(DT+DJ))*( Q(KOUNT)/          NOZZL033
     A (AREA(ICOMP-1)+AJET)*.5)**2                                       NOZZL034
      DELH(KOUNT,8)=XCORR*FRICT(RE)-XLNOZ*SIN(ANOZ)                      NOZZL035
```

```
      IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 2                            NOZZL036
      KOUNT=KOUNT+1                                                      NOZZL037
      GO TO 1                                                            NOZZL038
    3 WGTS(1,ICOMP)=1.E20                                                NOZZL039
      RETURN                                                             NOZZL040
C                                                                        NOZZL041
C     CENTER OF GRAVITY AND WEIGHT CALCULATIONS OF NOZZLE                NOZZL042
C                                                                        NOZZL043
    2 CGS(1,ICOMP)=HCL                                                   NOZZL044
      CGS(2,ICOMP)=XLPE-XLPS*(.25*DT*DT+.5*DT*DJ+.75*DJ*DJ)/(DT*DT+DT*DJNOZZL045
     A +DJ*DJ)                                                           NOZZL046
      CGS(3,ICOMP)=HCL                                                   NOZZL047
      CGS(4,ICOMP)=CGS(2,ICOMP)                                          NOZZL048
      WGTS(2,ICOMP)=XLPS/3.*(AREA(ICOMP-1)+AJET+SQRT(AREA(ICOMP-1)*AJET)NOZZL049
     A  )*RHOW*G                                                         NOZZL050
      AREA1=PI*.25*(.152*DT+.056**2)                                     NOZZL051
      AJET1=PI*.25*(.152*DJ+.056**2)                                     NOZZL052
      WGTS(1,ICOMP)=XLPS/3.*(AREA1+AJET1+SQRT(AREA1*AJET1))*RHOD*G*XPUMPNOZZL053
      IF(XFAC.GT.1.) RETURN                                              NOZZL054
      CGS(1,ICOMP)=.75*HCL                                               NOZZL055
      CGS(3,ICOMP)=CGS(1,ICOMP)                                          NOZZL056
      RETURN                                                             NOZZL057
      END                                                                NOZZL058
```

```
      SUBROUTINE PUMP
C
C     PUMP JET DESIGN PROGRAM
C
C     PUMP JET PROGRAM SOLVES THE PUMP, GEAR , AND FUEL WEIGHTS FOR
C       BOTH THE MULT-PARALLEL CENTRIFUGAL PUMP AND THE AXIAL PUMP
C     THE PUMP DESIGN WITH THE LEAST TOTAL WEIGHT IS GIVEN AS THE
C     OPTIMUM DESIGN FOR THE GIVEN INPUT PARAMETERS
C
      LOGICAL IFUEL,IPUMP
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
      COMMON /DRAG/TDRAG(5),STPTD(5),POD(5),SPRAY(5),REST(5),VO(5),
     1 TRIM(5)
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA
      COMMON /SHIP/ DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
      COMMON /CONST/PI,G,RHOD
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)
      COMMON /INDEX/IEVAL,IEOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT
      COMMON /WEGT/XWD(5),XWW(5),XWG(5),XWF(5)
      COMMON /PSUP/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)
      COMMON /PUMM/QQ(5),D1S(5),D2S(5),XNS(5),SM(5),PLP(5),NSTG,SHI(5),
     A XIM
      COMMON /HEAD/HPP(5),HSV(5),THOM(5),PHI(5),WF,WG
      COMMON /TOLER/DELTA
      COMMON IFUEL,IPUMP
      DIMENSION PC(2,3),PCA(2,3),PCC(2,3)
      DIMENSION  XRPM(11),XD1(11),XD2(11),RPK(11),XPUP(11),YLP(11),
     6XERAT(11),APUP(5),WRAT(5),WD(10),WW(10),WWG(10)
C
C     PUMP CHARCTERISTIC DATA
      DATA PC/-3.0,-1.7,4.8,3.42,-0.8,-0.720/
      DATA PCA/-1.0,-1.7,1.0,3.42, 1.0,-0.72/
      DATA PCC/-1.5,-0.75,1.0,1.51,1.0,0.24/
C
C     K = CRUISE POINT  , J = TAKE OFF POINT
C     PUMP DESIGN POINT,J, IS AT TAKE OFF BASED ON THOMA'S CRITERION
```

```
C       OFF DESIGN POINT,K, IS ANY OTHER POINT ALONG THE DRAG TO SPEED CURPUMP 036
        K=1                                                               PUMP 037
        J=2                                                               PUMP 038
        DO 4 I=1,5                                                        PUMP 039
      4 WRAT(I)=0.                                                        PUMP 040
        XPUMP=FLOAT(NPUMP)                                                PUMP 041
        DO2 I=1,2                                                         PUMP 042
        QQ(I)=Q(I)/XPUMP                                                  PUMP 043
        HPP(I)=(VJ(I)*VJ(I)-VO(I)*VO(I))/(2.*G)+DELH(I,7)+DELH(I,8)       PUMP 044
        HSV(I)=HA-DELH(I,7)+VO(I)*VO(I)/(2.*G)-PV                         PUMP 045
        THOM(I)=HSV(I)/HPP(I)                                             PUMP 046
      2 CONTINUE                                                          PUMP 047
        NSTG=1                                                            PUMP 048
        IF(HSV(J).LT.0.005)  GO TO 10                                     PUMP 049
C                                                                         PUMP 050
C       FOR THE VALUE ON THOMA'S CAVITATION CRITERION LESS THAN THE CUT   PUMP 051
C       OFF POINT, THOMI, THE INDUCER PLUS ONE AXIAL STAGE IS REQUIRED    PUMP 052
C                                                                         PUMP 053
        THOMI=0.055                                                       PUMP 054
        IF(THOM(J).LT.THOMI)  GO TO 201                                   PUMP 055
C                                                                         PUMP 056
C       SINGLE STAGE INDUCER DESIGN                                       PUMP 057
C       PUMP CHARACTERISTICS                                              PUMP 058
C       XNS IS THE SPECIFIC SPEED (CFS) FOR THE FIRST STAGE IN A MULTI-STAPUMP 059
C       DESIGN OR FOR ONE IMPELLER IN A MULTI-DOUBLE SUCTION IMPELLER DESIPUMP 060
C       SM IS THE MAXIMUM SUCTION SPECIFIC SPEED AT TAKE OFF .            PUMP 061
C                                                                         PUMP 062
    200 XNS(NSTG)=149.5                                                   PUMP 063
        SM(1)=XNS(1)*(1.0/THOM(J))**0.75                                  PUMP 064
        PHI(1)=0.11                                                       PUMP 065
        DRAT=0.30                                                         PUMP 066
        XXLP=1.73                                                         PUMP 067
        CW=347.1*XPUMP                                                    PUMP 068
C                                                                         PUMP 069
C       DESIGN POINT PUMP SPEED                                           PUMP 070
C                                                                         PUMP 071
```

```
      RPM(J,NSTG)=XNS(NSTG)*HPP(J)**0.75/SQRT(QQ(J))                    PUMP 072
C                                                                       PUMP 073
C     PUMP INLET TIP DIAMETER                                           PUMP 074
C                                                                       PUMP 075
      DIS(1)=(240.*QQ(J)/(9.4748*PHI(1)*(1.-DRAT**2)*RPM(J,1)))**(1./3.)PUMP 076
      SHI(1)=G*HPP(J)/(PI*RPM(J,1)*DIS(1)/60.)**2                       PUMP 077
      IF(SHI(NSTG).GT.0.41)  GO TO 201                                  PUMP 078
      ETAP(J,NSTG)=1.0-((3.666/DIS(NSTG))**0.165*(1.-.915))             PUMP 079
      QX=QQ(K)/QQ(J)                                                    PUMP 080
      ETAP(K,1)=ETAP(J,1)*(PC(2,1)*QX**2+PC(2,2)*QX+PC(2,3))            PUMP 081
C                                                                       PUMP 082
C     OFF DESIGN POINT PUMP RPM                                         PUMP 083
C                                                                       PUMP 084
      CA=PC(1,2)/PC(1,3)*0.5                                            PUMP 085
      CB=PC(1,1)/PC(1,3)                                                PUMP 086
      HX=HPP(K)/HPP(J)                                                  PUMP 087
      RX=-CA*QX-SQRT(QX*QX*(CA*CA-CB)+HX/PC(1,3))                       PUMP 088
      RPM(K,NSTG)=RPM(J,NSTG)*RX                                        PUMP 089
C                                                                       PUMP 090
C     PHRAT IS THE OFF DESIGN TO DESIGN FLOW COEFFICIENT RATIO, PHI(K)/PPUMP 091
C                                                                       PUMP 092
      PHRAT=QX/RX                                                       PUMP 093
C                                                                       PUMP 094
C     DRY PUMP WEIGHT                                                   PUMP 095
C                                                                       PUMP 096
  203 XWD(NSTG)=CW*DIS(NSTG)**2.3                                       PUMP 097
      PLP(NSTG)=DIS(NSTG)*XXLP                                          PUMP 098
      APUP(NSTG)=0.785*DIS(NSTG)**2*(1.-DRAT*DRAT)                      PUMP 099
      D2S(NSTG)=DIS(NSTG)                                               PUMP 100
C                                                                       PUMP 101
C     ENTRAINED WATER WEIGHT                                            PUMP 102
C                                                                       PUMP 103
      XWW(NSTG)=0.523*APUP(NSTG)*PLP(NSTG)*RHOW*G*XPUMP                 PUMP 104
      XNGT=NGT                                                          PUMP 105
      SHP(2,NSTG)=RHOW*G*Q(2)*HPP(2)/(550.*XNGT*ETAP(2,NSTG)*.98)       PUMP 106
      GERAT(NSTG)=PERF(4,IENGN)/RPM(J,NSTG)                             PUMP 107
```

```
      IF(GERAT(NSTG).LT.1..AND.DELTA.NE.0.) GO TO 16                    PUMP 108
      CALL GEAR                                                         PUMP 109
      XWG(NSTG)=WG                                                      PUMP 110
      DO 3 I=1,2                                                        PUMP 111
      ETAPP=ETAP(I,NSTG)*ETAP(7,NSTG)                                   PUMP 112
      SHP(I,NSTG)=RHOW*G*Q(I)*HPP(I)/(550.*XNGT*ETAPP)                  PUMP 113
    3 IF(SHP(I,NSTG).GT.PERF(I,IENGN).AND.DELTA.GT.1.E-9) XWW(NSTG)=1.E9PUMP 114
C                                                                       PUMP 115
      CALL FUEL                                                         PUMP 116
      XWF(NSTG)=WF                                                      PUMP 117
      WRAT(NSTG)=(XWD(NSTG)+XWW(NSTG)+XWG(NSTG)+XWF(NSTG))/DISP         PUMP 118
      GO TO 300                                                         PUMP 119
   16 XWG(NSTG)=1.E11                                                   PUMP 120
      GO TO 300                                                         PUMP 121
C                                                                       PUMP 122
C     INDUCER PLUS ONE AXIAL STAGE DESIGN                               PUMP 123
C                                                                       PUMP 124
  201 THOMI=0.058                                                       PUMP 125
      NSTG=2                                                            PUMP 126
      HP=HSV(J)/THOMI                                                   PUMP 127
C                                                                       PUMP 128
C     THOMS IS THOMA'S CAVITATION CRITERION FOR THE AXIAL STAGE         PUMP 129
C     BASED ON A MAXIMUM  S OF 10,000 AND NS=3619                       PUMP 130
C                                                                       PUMP 131
      THOMS=0.258                                                       PUMP 132
C                                                                       PUMP 133
C     INDUCER SPECIFIC SPEED AND FLOW COEFF.                            PUMP 134
C                                                                       PUMP 135
      XNS(NSTG)=149.5                                                   PUMP 136
      PHI(2)=0.15                                                       PUMP 137
      DRAT=0.3                                                          PUMP 138
      XXLP=1.71                                                         PUMP 139
      CW=393.5*XPUMP                                                    PUMP 140
C                                                                       PUMP 141
C     DESIGN PUMP SPEED                                                 PUMP 142
C                                                                       PUMP 143
```

```
      RPM(J,NSTG)=XNS(NSTG)*HP**0.75/SQRT(QQ(J))
C
C     PUMP INLET TIP DIAMETER
C
      D1S(2)=(240.*QQ(J)/(9.4748*PHI(2)*(1.-DRAT**2)*RPM(J,2)))**(1./3.)
      ETAP(J,NSTG)=1.0-((3.666/D1S(NSTG))**0.165*(1.-.915))
      QX=QQ(K)/QQ(J)
      ETAP(K,NSTG)=ETAP(J,NSTG)*(PCA(2,1)*QX**2+PCA(2,2)*QX+PCA(2,3))
C
C     OFF DESIGN POINT RPM
C
      CA=PCA(1,2)/PCA(1,3)*0.5
      CB=PCA(1,1)/PCA(1,3)
      HX=HPP(K)/HPP(J)
      RX=-CA*QX+SQRT(QX*QX*(CA*CA-CB)+HX/PCA(1,3))*(CA/ABS(CA))
      RPM(K,NSTG)=RPM(J,NSTG)*RX
      PHRAT=QX/RX
      SM(NSTG)=XNS(NSTG)*(HP/HSV(J))**0.75
      IF((HSV(J)+HP)/(HPP(J)-HP).LT.THOMS)   GO TO 202
      SHI(2)=G*HP/(PI*RPM(J,2)*D1S(2)/60.)**2
      GO TO 203
C
C     INDUCER PLUS TWO AXIAL STAGES DESIGN
C
  202 HHP=(HPP(J)-HP)/2.0
      NSTG=3
      XXLP=2.03
      CW=439.5*XPUMP
      XNS(3)=XNS(2)
      SM(3)=SM(2)
      D1S(3)=D1S(2)
      SHI(3)=SHI(2)
      PHI(3)=PHI(2)
      RPM(J,3)=RPM(J,2)
      RPM(K,3)=RPM(K,2)
      ETAP(J,3)=ETAP(J,2)
```

```
      ETAP(K,3)=ETAP(K,2)
      IF(((HSV(J)+HP)/HHP).LT.THOMS)   GO TO 10
      GO TO 203
C
C     MULTI PARALLEL IMPELLER DESIGN
C
  300 NSTG=4
      SM(4)=424.5
C
C     PUMP CHARACTERISTICS
C     THE CENTRIFUGAL IMPELLER DESIGN IS BASED ON A CONSTANT IMPELLER
C     EXIT ANGLE OF 22 DEGREES AND A HYDRAULIC EFFICIENCY OF 0.90
C
      DRAT=0.50
      BETA2=2.477
      XNS(4)=SM(4)*THOM(J)**0.75
      XNNS=XNS(4)/811.3
C
C     THE IMPELLER EXIT WIDTH RATIO IS ASSUMMED TO BE LINEAR WITH NS
C
      BD=0.001*XNS(4)-0.025
      IF(XNS(4).LT.50.)  BD=0.025
      CC=SQRT(BD/PI)
      PHI(4)=0.06
   14 AA=CC*SQRT(PHI(4))/(0.9*(1.-PHI(4)*BETA2))**0.75
      IF((XNNS-AA).LE.0.005)  GO TO 15
      PHI(4)=PHI(4)+0.005
      GO TO 14
   15 SHI(4)=0.90*(1.-PHI(4)*2.414)
C
C     SPECIFIC SPEED AND PUMP CHARAC. ARE FOR A SINGLE IMPELLER
C
      PCC(1,3)=XNS(4)/283.85-.17
      PCC(1,2)=2.5-PCC(1,3)
C
      IMPL=10
```

```
      DO 5 M=1,IMPL                                                     PUMP 216
C     XIM EQUALS THE NUMBER OF DOUBLE SUCTION IMPELLERS                 PUMP 217
      XIM=FLOAT(M)                                                      PUMP 218
      QQ(J)=Q(J)/(2.0*XIM*XPUMP)                                        PUMP 219
      QQ(K)=Q(K)/(2.0*XIM*XPUMP)                                        PUMP 220
      QX=QQ(K)/QQ(J)                                                    PUMP 221
      XRPM(M)=XNS(4)*HPP(J)**0.75/SQRT(QQ(J))                           PUMP 222
      XD1(M)=(240.*QQ(J)/(9.4748*0.2500*(1.-DRAT**2)*XRPM(M)))**(1./3.) PUMP 223
      XD2(M)=60.0*SQRT(G*HPP(J)/SHI(4))/(PI*XRPM(M))                    PUMP 224
C     OFF DESIGN POINT RPM                                              PUMP 225
      CA=PCC(1,2)/PCC(1,3)*0.5                                          PUMP 226
      CB=PCC(1,1)/PCC(1,3)                                              PUMP 227
      HX=HPP(K)/HPP(J)                                                  PUMP 228
      RX=-CA*QX+SQRT(QX*QX*(CA*CA-CB)+HX/PCC(1,3))*(CA/ABS(CA))         PUMP 229
      RPK(M)=XRPM(M)*RX                                                 PUMP 230
C                                                                       PUMP 231
      ETAP(J,4)=1.0-((2.333/XD2(M))**0.165*(1.-.830))                   PUMP 232
      ETAP(K,4)=ETAP(J,4)*(PCC(2,1)*QX*QX+PCC(2,2)*QX+PCC(2,3))         PUMP 233
C                                                                       PUMP 234
C     PUMP WEIGHT                                                       PUMP 235
C                                                                       PUMP 236
      XPUP(M)=101.91*Q(J)/(XRPM(M)*XD1(M)*XPUMP)                        PUMP 237
      YLP(M)=SQRT(XPUP(M)/(XIM*0.366))*(1.+XIM)                         PUMP 238
      CW=6.46                                                           PUMP 239
      WD(M)=(XIM*.725+.275)*CW*XD2(M)*XD2(M)*XNS(4)*XPUMP               PUMP 240
      WW(M)=0.55*WD(M)                                                  PUMP 241
C                                                                       PUMP 242
C                                                                       PUMP 243
      SHP(2,NSTG)=RHOW*G*Q(2)*HPP(2)/(550.*XNGT*ETAP(2,NSTG)*.98)       PUMP 244
      XERAT(M)=PERF(4,IENGN)/XRPM(M)                                    PUMP 245
      GERAT(4)=XERAT(M)                                                 PUMP 246
      CALL GEAR                                                         PUMP 247
      WWG(M)=WG                                                         PUMP 248
      DO 7 I=1,2                                                        PUMP 249
      ETAPP=ETAP(I,NSTG)*ETAP(7,NSTG)                                   PUMP 250
      SHP(I,NSTG)=RHOW*G*Q(I)*HPP(I)/(550.*XNGT*ETAPP)                  PUMP 251
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```
    7 IF(SHP(I,NSTG).GT.PERF(I,IENGN).AND.DELTA.GT.1.E-9) WW(M)=1.E9      PUMP 252
      IF(M.EQ.1) GO TO 5                                                  PUMP 253
      IF(THOM(J).LT.0.046)  GO TO 12                                      PUMP 254
      IF(XERAT(M).LE.1.0)  GO TO 5                                        PUMP 255
      IF((WD(M)+WW(M)+WWG(M)).GT.(WD(M-1)+WW(M-1)+WWG(M-1))) GO TO 6      PUMP 256
    5 CONTINUE                                                            PUMP 257
      M=IMPL+1                                                            PUMP 258
      GO TO 6                                                             PUMP 259
   12 WD(M-1)=1.E9                                                        PUMP 260
    6 XWD(4)=WD(M-1)                                                      PUMP 261
      XWW(4)=WW(M-1)                                                      PUMP 262
      XWG(4)=WWG(M-1)                                                     PUMP 263
      XIM=M-1                                                             PUMP 264
      RPM(J,4)=XRPM(M-1)                                                  PUMP 265
      D1S(4)=XD1(M-1)                                                     PUMP 266
      D2S(4)=XD2(M-1)                                                     PUMP 267
      RPM(K,4)=RPK(M-1)                                                   PUMP 268
      APUP(4)=XPUP(M-1)                                                   PUMP 269
      PLP(4)=YLP(M-1)                                                     PUMP 270
      GERAT(4)=XERAT(M-1)                                                 PUMP 271
      IF(GERAT(4).LT.1..AND.DELTA.GT.1.E-9)  XWG(4)=1.E9                  PUMP 272
      CALL FUEL                                                           PUMP 273
      XWF(4)=WF                                                           PUMP 274
C                                                                         PUMP 275
C     TOTAL WEIGHT TO DISPLACEMENT RATIO                                  PUMP 276
C                                                                         PUMP 277
      WRAT(NSTG)=(XWD(NSTG)+XWW(NSTG)+XWG(NSTG)+XWF(NSTG))/DISP           PUMP 278
      N=4                                                                 PUMP 279
      DO 8  M=1,3                                                         PUMP 280
      IF(WRAT(M).NE.0.) GO TO 9                                           PUMP 281
    8 CONTINUE                                                            PUMP 282
    9 CONTINUE                                                            PUMP 283
      IF(WRAT(M).GT.WRAT(N)) M=N                                          PUMP 284
      NSTG=M                                                              PUMP 285
      XLP=PLP(NSTG)                                                       PUMP 286
      IPUMP=.NOT.IPUMP                                                    PUMP 287
```

```
      WGTS(1,8)=XWD(M)                                                  PUMP 288
      WGTS(2,8)=XWW(M)                                                  PUMP 289
      WGTS(1,10)=XWG(M)                                                 PUMP 290
      WGTS(2,11)=XWF(M)                                                 PUMP 291
      CGS(1,ICOMP)=HCL                                                  PUMP 292
      CGS(2,ICOMP)=XLPF+XLP*.5                                          PUMP 293
      CGS(3,ICOMP)=HCL                                                  PUMP 294
      CGS(4,ICOMP)=CGS(2,ICOMP)                                         PUMP 295
      AREA(8)=APUP(NSTG)*XPUMP                                          PUMP 296
      IF(NSTG.NE.4) XIM=NSTG-1                                          PUMP 297
      RETURN                                                            PUMP 298
   10 WGTS(1,8)=1.E10                                                   PUMP 299
      RETURN                                                            PUMP 300
      END                                                               PUMP 301
```

```
      SUBROUTINE GEAR                                                   GEAR 000
      COMMON /INDEX/IEVAL,IEOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT  GEAR 001
      COMMON /CONST/PI,G,RHOO                                           GEAR 002
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)      GEAR 003
      COMMON /PUMM/QQ(5),D1S(5),D2S(5),XNS(5),SM(5),PLP(5),NSTG,SHI(5), GEAR 004
     A XIM                                                              GEAR 005
      COMMON /HEAD/HPP(5),HSV(5),THOM(5),PHI(5),WF,WG                   GEAR 006
C                                                                       GEAR 007
C     GEAR PUMP ARRANGEMENT.  IF NO. OF PUMPS =S NO. OF GTS , A PLANETARGEAR 008
C     WILL BE USED.  IF TWO PUMPS PER GT OR TWO GTS PER  PUMP A COMBININGEAR 009
C     REDUCTION GEAR WITH IDLER WILL BE USED.                           GEAR 010
C                                                                       GEAR 011
      GRAT=GERAT(NSTG)                                                  GEAR 012
      IF(GRAT.GT.12.)  GO TO 12                                         GEAR 013
      IF(NGT-NPUMP) 100,101,102                                         GEAR 014
C                                                                       GEAR 015
C     SUBROUTINE FOR SINGLE REDUCTION GEAR WITH IDLER                   GEAR 016
C                                                                       GEAR 017
  100 FAC=1.7                                                           GEAR 018
      GO TO 3                                                           GEAR 019
  102 FAC=1.3                                                           GEAR 020
    3 IF(GRAT.GT.1.0) GO TO 1                                           GEAR 021
      GRAT=1.0                                                          GEAR 022
    1 C=GRAT*GRAT+1.0                                                   GEAR 023
      D=SQRT(C*C/64.0+0.00463)                                          GEAR 024
      DX =C*0.25-D                                                      GEAR 025
      X=(C*0.25+D)**(1.0/3.0)+DX/ABS(DX)*ABS(DX)**(1.0/3.0)             GEAR 026
      FD=(1.0+GRAT**2.0)*(1.0+1.0/X)+X*(1.0+X)                          GEAR 027
      WG=FAC*88.2*FD*SHP(2,NSTG)/PERF(4,IENGN)*ABS(FLOAT(NGT-NPUMP))    GEAR 028
      ETAP(7,NSTG)=0.98                                                 GEAR 029
      GO TO 2                                                           GEAR 030
C                                                                       GEAR 031
C     SUBROUTINE FOR PLANETARY GEAR WEIGHT                              GEAR 032
C     ASSUMED. K FACTOR = 500                                           GEAR 033
C     ALLOCATION FACTOR = 0.35                                          GEAR 034
C                                                                       GEAR 035
```

```
101 IF(GRAT.GT.1.5)  GO TO 8                                          GEAR 036
    WG=0.0                                                            GEAR 037
    ETAP(7,NSTG)=1.0                                                  GEAR 038
    GO TO 2                                                           GEAR 039
  8 IF(GRAT.GT.2.05)  GO TO 9                                         GEAR 040
    GRAT=2.05                                                         GEAR 041
  9 IF(GRAT.GT.4.0)  GO TO 10                                         GEAR 042
    B=6.0                                                             GEAR 043
    GO TO 11                                                          GEAR 044
 10 B=PI/ARSIN((GRAT-2.0)/GRAT)                                       GEAR 045
 11 C=0.4*(GRAT-1.0)*(GRAT-1.0)                                       GEAR 046
    E=(C+1.0)/B*0.5                                                   GEAR 047
    D=SQRT(.25*(.25/27.-E)**2-1./43356.)                              GEAR 048
    DX=-(.25/27.-E)*0.5-D                                             GEAR 049
    X=(-(.25/27.-E)*.5+D)**(1./3.)+DX/ABS(DX)*ABS(DX)**(1./3.)        GEAR 050
    FD=1./B*(1.+1./X)*(1.+X*X*B+C)                                    GEAR 051
    WG=88.2*FD*SHP(2,NSTG)/PERF(4,IENGN)*FLOAT(NPUMP)                 GEAR 052
    ETAP(7,NSTG)=0.98                                                 GEAR 053
    GO TO 2                                                           GEAR 054
C                                                                     GEAR 055
C   DOUBLE REDUCTION DOUBLE BRANCH GEAR DESIGN                        GEAR 056
C   GEAR BASED ON A K FACTOR OF 300                                   GEAR 057
C                                                                     GEAR 058
 12 IF(NGT-NPUMP)  103,104,105                                        GEAR 059
103 FAC=1.7*FLOAT(NPUMP-NGT)                                          GEAR 060
    GO TO 13                                                          GEAR 061
104 FAC=1.0*FLOAT(NPUMP)                                              GEAR 062
    GO TO 13                                                          GEAR 063
105 FAC=1.3*FLOAT(NGT-NPUMP)                                          GEAR 064
 13 A=GRAT/(GRAT+1.0)                                                 GEAR 065
    C=(GRAT*GRAT+1.0)*0.25                                            GEAR 066
    D=SQRT((2.*A**3/27.-A*C)**2*.25-A**6/729.)                        GEAR 067
    E=-2.*A**3/27.+A*C                                                GEAR 068
    DX=(E-D)**(1./3.)                                                 GEAR 069
    X=(E+D)**(1./3.)+DX/ABS(DX)*ABS(DX)**(1./3.)                      GEAR 070
    FD=.5*(1.+1./X+4.*X+2.*X*X*(1.+1./GRAT)+2.*GRAT*GRAT/X+GRAT)      GEAR 071
```

```
      WG=FAC*147.*FD*SHP(2,NSTG)/PERF(4,IENGN)                          GEAR 072
      ETAP(7,NSTG)=0.93                                                  GEAR 073
    2 CONTINUE                                                           GEAR 074
      RETURN                                                             GEAR 075
      END                                                                GEAR 076
```

```
      SUBROUTINE FUEL                                                   FUEL 000
C     FUEL WEIGHT AT CONSTANT SPEED ASSUMMING SFC = CSF*SHP TO 1/4 AND EFUEL 001
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           FUEL 002
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   FUEL 003
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),     FUEL 004
     1 TRIM(5).                                                         FUEL 005
      COMMON /SHIP/ DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP              FUEL 006
      COMMON /CONST/PI,G,RHOD                                           FUEL 007
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   FUEL 008
      COMMON /INDEX/IEVAL,IEOPT,ISTPT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT  FUEL 009
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)      FUEL 010
      COMMON /PUMP/QQ(5),D1S(5),D2S(5),XNS(5),SM(5),PLP(5),NSTG,SHI(5), FUEL 011
     A XIM                                                              FUEL 012
      COMMON /HEAD/HPP(5),HSV(5),THOM(5),PHI(5),WF,WG                   FUEL 013
      DIMENSION WT(21),DIS(21),VJJ(21)                                  FUEL 014
C                                                                       FUEL 015
C     FUEL CALCULATIONS BASED ON CONSTANT SPEED THROUGHOUT RANGE. DURATIFUEL 016
C     TRAVEL DIVIDED INTO 20 SEGMENTS AND FUEL WEIGHT CALCULATED ON REVIFUEL 017
C     SHP REQUIREMENTS DUE TO WEIGHT DECREASE                           FUEL 018
C                                                                       FUEL 019
      CFS=PERF(3,IENGN)*PERF(1,IENGN)**0.25                             FUEL 020
      CA=TDRAG(1)/DISP                                                  FUEL 021
      CD=1.0+ (DELH(1,8) +DELH(1,7))*2.0*G/(VJ(1)*VJ(1))                FUEL 022
      WT(1)=0.0                                                         FUEL 023
      DIS(1)=DISP                                                       FUEL 024
      N=21                                                              FUEL 025
      XN=20.                                                            FUEL 026
      TI=RANGE/(VO(1)*XN)*1.689                                         FUEL 027
      IJK=0                                                             FUEL 028
      XJ=0.75                                                           FUEL 029
      DO 1 I=2,N                                                        FUEL 030
      DIS(I)=DIS(I-1)-WT(I-1)                                           FUEL 031
      VJJ(I)=VO(1)/2.0+SQRT(VO(1)**2/4.0+DIS(I)*CA/(RHOW*AJET))         FUEL 032
      H=CD*VJJ(I)*VJJ(I)/(2.*G)-VO(1)*VO(1)/(2.*G)+HE                   FUEL 033
      SHPP=(RHOW*G*AJET*VJJ(I)*H)/(550.*ETAP(1,NSTG)*ETAP(7,NSTG))      FUEL 034
      SHNG=SHPP/FLOAT(NGT)                                              FUEL 035
```

```
      IF(SHNG.GT.0.7*PERF(1,IENGN).OR.IJK.EQ.1)  GO TO 4                FUEL 036
      CFS=CFS*SQRT(SHNG)                                                  FUEL 037
      IJK=1                                                               FUEL 038
      XJ=0.25                                                             FUEL 039
    4 WT(I)=CFS*TI*SHPP**XJ*FLOAT(NGT)**(1.-XJ)                           FUEL 040
    1 CONTINUE                                                            FUEL 041
      DO2 M=2,N                                                           FUEL 042
    2 WT(M)=WT(M)+WT(M-1)                                                 FUEL 043
      WF=WT(N)                                                            FUEL 044
      RETURN                                                              FUEL 045
      END                                                                 FUEL 046
```

```
      FUNCTION CFS(R)
C
C     SCHOENHERR SKIN FRICTION COEFFICIENT
C
      CFS=0.004
    1 DCFS=(0.242/ALOG10(R*CFS))**2-CFS
      CFS=CFS+DCFS
      IF(DCFS.GT.1.E-6) GO TO 1
      RETURN
      END
```

```
      FUNCTION TABLE(XTAB,YTAB,XIN,L)                                   TABLE000
      DIMENSION XTAB(2),YTAB(2),X(5),Y(5),A(5),B(5),L(2)                TABLE001
C                                                                       TABLE002
C     L(1)     - NUMBER OF PAIRS OF DATA POINTS ENTERED                 TABLE003
C     L(2)     - DEGREE OF FIT, MAXIMUM IS FOUR                         TABLE004
C     XTAB     - DATA ARRAY OF X VALUES                                 TABLE005
C     YTAB     - DATA ARRAY OF Y VALUES                                 TABLE006
C     XIN      - INDEPENDENT VARIABLE                                   TABLE007
C     TABLE    - DEPENDENT VARIABLE CORRESPONDING TO XIN                TABLE008
C                                                                       TABLE009
      NPTS=L(1)                                                         TABLE010
      K=L(2)+1                                                          TABLE011
      IF(K.GT.NPTS) K=NPTS                                              TABLE012
C                                                                       TABLE013
C     BRANCH TO TEN IF X IS INCREASING                                  TABLE014
C     BRANCH TO 160 IF X IS DECREASING                                  TABLE015
C     IF XTAB(1).EQ.XTAB(2) ABORT RUN                                   TABLE016
C                                                                       TABLE017
      IF(XTAB(1)-XTAB(2)) 10,290,160                                    TABLE018
   10 IF(XTAB(1)-XIN) 20,140,200                                        TABLE019
   20 DO 120 IX=2,NPTS                                                  TABLE020
C                                                                       TABLE021
C     FIND XTAB VALUES BRACKETING XIN                                   TABLE022
C                                                                       TABLE023
      IF(XTAB(IX).LE.XTAB(IX-1)) GO TO 290                              TABLE024
      IF(XTAB(IX)-XIN) 120,150,40                                       TABLE025
  120 CONTINUE                                                          TABLE026
      GO TO 130                                                         TABLE027
   40 CONTINUE                                                          TABLE028
C                                                                       TABLE029
C     IF XIN LIES BETWEEN EITHER END POINT OF THE XTAB ARRAY AND ITS    TABLE030
C     ADJACENT POINT, THE INTERPOLATION IS LIMITED TO A SECOND DEGREE   TABLE031
C     FIT                                                               TABLE032
      IF(IX.GT.2) GO TO 60                                              TABLE033
      IF(K.GT.3) K=3                                                    TABLE034
   60 IF(IX.LT.NPTS) GO TO 80                                           TABLE035
```

```
      IF(K.GT.3) K=3                                                    TABLE036
   80 NDX=IX-K/2                                                        TABLE037
      IF(IX.LT.NPTS) GO TO 100                                          TABLE038
      NDX=NPTS-K+1                                                      TABLE039
  100 DO 110 IL=1,K                                                     TABLE040
C                                                                       TABLE041
C     XTAB  AND YTAB VALUES FOR THE XTAB VALUES BRACKETING XIN ARE      TABLE042
C     TRANSFERRED TO THE LAGRANGIAN EQUATION                            TABLE043
C                                                                       TABLE044
      X(IL)=XTAB(NDX)                                                   TABLE045
      Y(IL)=YTAB(NDX)                                                   TABLE046
      NDX=NDX+1                                                         TABLE047
  110 CONTINUE                                                          TABLE048
      GO TO 210                                                         TABLE049
  130 CONTINUE                                                          TABLE050
C                                                                       TABLE051
C     TO GET PAST STATEMENT NUMBER 120, XIN IS LARGER THAN THE LARGEST  TABLE052
C     VALUE OF X IN XTAB. EXTRAPOLATION IS NECESSARY TO FIND TABLE AT   TABLE053
C     XIN                                                               TABLE054
      TABLE=((YTAB(NPTS)-YTAB(NPTS-1))/(XTAB(NPTS)-XTAB(NPTS-1)))*      TABLE055
     A (XIN-XTAB(NPTS))+YTAB(NPTS)                                      TABLE056
      RETURN                                                            TABLE057
  140 IX=1                                                              TABLE058
  150 TABLE=YTAB(IX)                                                    TABLE059
      RETURN                                                            TABLE060
  160 IF(XIN-XTAB(1)) 170,140,200                                       TABLE061
  170 DO 190 IX=2,NPTS                                                  TABLE062
C                                                                       TABLE063
C     XTAB IS SEARCHED TO FIND THE VALUE CLOSEST TO XIN                 TABLE064
C                                                                       TABLE065
      IF(XTAB(IX).GE.XTAB(IX-1)) GO TO 290                              TABLE066
      IF(XIN-XTAB(IX)) 190,150,40                                       TABLE067
  190 CONTINUE                                                          TABLE068
      GO TO 130                                                         TABLE069
C                                                                       TABLE070
C     TO GO TO STATEMENT NUMBER 130 INDICATES XIN IS SMALLER THAN THE   TABLE071
```

```
C     SMALLEST VALUE OF X IN XTAB AND EXTRAPOLATION IS NECESSARY TO FINDTABLE072
C     TABLE FOR XIN                                                     TABLE073
  200 TABLE=((YTAB(2)-YTAB(1))/(XTAB(2)-XTAB(1)))*(XIN-XTAB(1))+YTAB(1) TABLE074
      RETURN                                                            TABLE075
  210 DO 220 LL=1,K                                                     TABLE076
      A(LL)=1.                                                          TABLE077
  220 B(LL)=1.                                                          TABLE078
      P=0.                                                              TABLE079
C                                                                       TABLE080
C     PERFORM LAGRANGIAN INTERPOLATION                                  TABLE081
C                                                                       TABLE082
      DO 280 N=1,K                                                      TABLE083
      DO 270 J=1,K                                                      TABLE084
      AA=XIN-X(J)                                                       TABLE085
      IF(J.EQ.N) GO TO 240                                              TABLE086
      A(N)=A(N)*AA                                                      TABLE087
  240 BB=X(N)-X(J)                                                      TABLE088
      IF(BB.EQ.0.) GO TO 270                                            TABLE089
      B(N)=B(N)*BB                                                      TABLE090
  270 CONTINUE                                                          TABLE091
      C=A(N)/B(N)*Y(N)                                                  TABLE092
  280 P=P+C                                                             TABLE093
      TABLE=P                                                           TABLE094
      RETURN                                                            TABLE095
C                                                                       TABLE096
C     EQUAL CONSECUTIVE OR NON-MONOTONIC VALUES OF X ENCOUNTERED IN XTABTABLE097
C                                                                       TABLE098
  290 TABLE=1.E30                                                       TABLE099
      RETURN                                                            TABLE100
      END                                                               TABLE101
```

```
      SUBROUTINE PTTRN(PSI,SPSI,N,FCT,DEL,DLMIN)                        PTTRN000
C     ..................................................................PTTRN001
C        SUBROUTINE PTTRN                                               PTTRN002
C        PURPOSE                                                       .PTTRN003
C           TO FIND THE MINIMUM OF A FUNCTION BY DIRECT SEARCH          PTTRN004
C                                                                       PTTRN005
C        USAGE                                                          PTTRN006
C           CALL PTTRN(PSI,SPSI,N,FCT,DEL,DELMIN)                       PTTRN007
C                                                                       PTTRN008
C        DESCRIPTION OF PARAMETERS                                      PTTRN009
C           PSI    - A LINEAR ARRAY OF LENGTH N OF COORDINATES OF THE   PTTRN010
C                    ORIGIN OF SEARCH, INPUT                            PTTRN011
C           SPSI   - THE MINIMUM VALUE OF THE FUNCTION, OUTPUT          PTTRN012
C           N      - THE NUMBER OF PARAMETERS (COORDINATES) OF THE      PTTRN013
C                    FUNCTION, INPUT                                    PTTRN014
C           FCT    - THE FUNCTION SUBPROGRAM CONTAINING THE FUNCTION TO PTTRN015
C                    BE MINIMIZED                                       PTTRN016
C           DEL    - A LINEAR ARRAY OF LENGTH N CONTAINING THE INITIAL  PTTRN017
C                    STEP SIZE TO BE USED, INPUT                        PTTRN018
C           DLMIN  - A LINEAR ARRAY OF LENGTH N CONTAINING THE MINIMUM  PTTRN019
C                    STEP SIZES TO BE USED, INPUT                       PTTRN020
C                                                                       PTTRN021
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED                  PTTRN022
C           FCT                                                         PTTRN023
C                                                                       PTTRN024
C        REMARKS                                                        PTTRN025
C           THE CALLING PROGRAM MUST DECLARE THE FUNCTION SUBPROGRAM    PTTRN026
C           FCT IN AN EXTERNAL STATEMENT                                PTTRN027
C                                                                       PTTRN028
C           THIS SUBROUTINE IS A MODIFIED VERSION OF THAT SUGGESTED BY  PTTRN029
C           HOOKE AND JEEVES AND FOLLOWS THE NOTATION OF THAT PAPER     PTTRN030
C                                                                       PTTRN031
C        REFERENCES                                                     PTTRN032
C           1. HOOKE AND JEEVES, JACM,8(2),APR 61,PP 212-229            PTTRN033
C           2. ALGORITHM 178 AND SUBSEQUENT REMARKS, CACM               PTTRN034
C                                                                       PTTRN035
```

```
C     ..................................................................PTTRN036
C                                                                       PTTRN037
      DIMENSION PSI(1),THETA(9),PHI(9),DEL(1),DLMIN(1),DIR(9),SAVE(9)   PTTRN038
      DATA RHO/.5/                                                      PTTRN039
C                                                                       PTTRN040
C     EVALUATE THE FUNCTION AT THE INITIAL POINT                        PTTRN041
C                                                                       PTTRN042
      DO 5 K=1,N                                                        PTTRN043
    5 DIR(K)=0.                                                         PTTRN044
      SPSI=FCT(PSI)                                                     PTTRN045
C                                                                       PTTRN046
C     SET THE BASEPOINT                                                 PTTRN047
C                                                                       PTTRN048
    1 S=SPSI                                                            PTTRN049
      DO 10 I=1,N                                                       PTTRN050
   10 PHI(I)=PSI(I)                                                     PTTRN051
C                                                                       PTTRN052
C     ICALL=1 INDICATES THE BASEPOINT HAS JUST BEEN UPDATED             PTTRN053
C                                                                       PTTRN054
      ICALL=1                                                           PTTRN055
C                                                                       PTTRN056
C     MAKE EXPLORATORY MOVES FROM THE BASEPOINT                         PTTRN057
C                                                                       PTTRN058
      GO TO 99                                                          PTTRN059
C                                                                       PTTRN060
C     STORE PREVIOUS POINTS                                             PTTRN061
C                                                                       PTTRN062
    2 SPSI=S                                                            PTTRN063
      DO 11 I=1,N                                                       PTTRN064
      THETA(I)=PSI(I)                                                   PTTRN065
      PSI(I)=PHI(I)                                                     PTTRN066
C                                                                       PTTRN067
C     MAKE PATTERN MOVE (I.E. SIMULTANEOUSLY MOVE THE DISTANCE FROM THE PTTRN068
C     BASEPOINT TO THE PRESENT POINT IN EACH COORDINATE)                PTTRN069
C                                                                       PTTRN070
   11 PHI(I)=2.*PHI(I)-THETA(I)                                         PTTRN071
```

```
      SPHI=FCT(PHI)                                                     PTTRN072
      S=SPHI                                                            PTTRN073
C                                                                       PTTRN074
C     ICALL=2 INDICATES PATTERN MOVE JUST MADE                          PTTRN075
C                                                                       PTTRN076
      ICALL=2                                                           PTTRN077
C                                                                       PTTRN078
C     MAKE EXPLORATORY MOVES FROM RESULTING POINT OF PATTERN MOVE       PTTRN079
C                                                                       PTTRN080
      GO TO 33                                                          PTTRN081
C                                                                       PTTRN082
C     DECREMENT STEP SIZE BY A FACTOR OF RHO                            PTTRN083
C                                                                       PTTRN084
    3 NUMB=0                                                            PTTRN085
      DO 31 I=1,N                                                       PTTRN086
      IF(DEL(I).GT.DLMIN(I)) GO TO 31                                   PTTRN087
      NUMB=NUMB+1                                                       PTTRN088
   31 DEL(I)=RHO*DEL(I)                                                 PTTRN089
C                                                                       PTTRN090
C     IF ALL STEP SIZES ARE LESS THAN MINIMUM, RETURN TO CALLING PROGRAMPTTRN091
C     OTHERWISE, START OFF FROM BASEPOINT WITH SMALLER STEP             PTTRN092
C                                                                       PTTRN093
      IF(NUMB.EQ.N) RETURN                                              PTTRN094
      GO TO 1                                                           PTTRN095
C                                                                       PTTRN096
C     MAKE EXPLORATORY MOVES                                            PTTRN097
C                                                                       PTTRN098
   33 DO 35 K=1,N                                                       PTTRN099
      SAVE(K)=PHI(K)                                                    PTTRN100
C                                                                       PTTRN101
C     ASSIGN THE DIRECTION OF LAST IMPROVEMENT TO THE CURRENT STEP      PTTRN102
C                                                                       PTTRN103
      SIGN=DEL(K)                                                       PTTRN104
      IF(DIR(K).NE.0.) SIGN=DIR(K)/ABS(DIR(K))*DEL(K)                   PTTRN105
      PHI(K)=SAVE(K)+SIGN                                               PTTRN106
      SPHI=FCT(PHI)                                                     PTTRN107
```

```
      IF(SPHI.LT.S) GO TO 96                                          PTTRN108
      PHI(K)=SAVE(K)-SIGN                                             PTTRN109
      SPHI=FCT(PHI)                                                   PTTRN110
      IF(SPHI.LT.S) GO TO 96                                          PTTRN111
      PHI(K)=SAVE(K)                                                  PTTRN112
      GO TO 95                                                        PTTRN113
   96 S=SPHI                                                          PTTRN114
   95 CONTINUE                                                        PTTRN115
C                                                                     PTTRN116
C     IF A EXPLORATORY MOVE IS SUCCESSFUL TRY A PATTERN MOVE IN THAT  PTTRN117
C     DIRECTION. IF ALL EXPLORATORY MOVES ARE UNSUCCESSFUL, DECREASE  PTTRN118
C     STEPSIZE AND RESET BASEPOINT                                    PTTRN119
C                                                                     PTTRN120
C     FOR NORMAL USE OF PTTRN, THE FOLLOWING STATEMENT SHOULD READ    PTTRN121
C     IF(S.GT.SPSI) GO TO (3,1),ICALL                                 PTTRN122
      IF(S.GT.SPSI-100.) GO TO (3,1),ICALL                            PTTRN123
C                                                                     PTTRN124
C     DIR(K) CONTAINS THE SIZE AND DIRECTION OF THE LAST IMPROVEMENT  PTTRN125
C                                                                     PTTRN126
      DO 97 K=1,N                                                     PTTRN127
   97 DIR(K)=PHI(K)-SAVE(K)                                           PTTRN128
      GO TO 2                                                         PTTRN129
      END                                                             PTTRN130
```

```
      SUBROUTINE OUTPUT                                                 OUTPT000
      INTEGER ENGN(3,12)                                                OUTPT001
      LOGICAL IFUEL,IPUMP                                               OUTPT002
      COMMON /DRAG/TDRAG(5),STRTD(5),POD(5),SPRAY(5),REST(5),VO(5),     OUTPT003
     1 TRIM(5)                                                          OUTPT004
      COMMON /CONST/ PI,G,RHOD                                          OUTPT005
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   OUTPT006
      COMMON /SHIP/ DISP,RANGE,BEAM,HS,HF,HCL,XLS,XLPF,XLP              OUTPT007
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   OUTPT008
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           OUTPT009
      COMMON /STRTC/TC,T,C,T1,C1,CFM                                    OUTPT010
      COMMON /PUMM/OO(5),D1S(5),D2S(5),XNS(5),SM(5),PLP(5),NSTG,SHI(5), OUTPT011
     A XIN                                                              OUTPT012
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)      OUTPT013
      COMMON /HEAD/HPP(5),HSV(5),THOM(5),PHI(5),WF,WG                   OUTPT014
      COMMON /FLBW/XK(4),RD(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           OUTPT015
      COMMON /NACLL/DRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN        OUTPT016
      COMMON /INDEX/IEVAL,IEOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT  OUTPT017
      COMMON IFUEL,IPUMP                                                OUTPT018
      DIMENSION VJRAT(5),VIRAT(5),HEADL(5,15),CONDS(2,3),ELBWS(2,4),    OUTPT019
     A PC(5),LABEL(5,14)                                                OUTPT020
      DATA CONDS/4H CRU,4HISE ,4H T/O,4H     ,4H EVA,4HL    /           OUTPT021
      DATA ELBWS/4H STE,4HUT  ,4H HUL,4HL    ,4H PUM,4HP    ,4H DIV,4HERGEOUTPT022
     A /                                                                OUTPT023
      DATA HEADL/75*0./                                                 OUTPT024
      DATA LABEL/4HNACE,4HLLE ,3*4H    ,4HSTRU,4HT FL,4HBOW ,2*4H    ,  OUTPT025
     A 4HSTRU,4HT DI,4HFFUS,4HER  ,4H    ,4HHULL,4H FLB,4HOW  ,2*4H    ,OUTPT026
     B 4HATHW,4HARTS,4HHIPS,4H LEN,4HGTH ,4HPUMP,4H ELB,4HOW  ,2*4H    ,OUTPT027
     C 4HFORE,4H AND,4H AFT,4H LEN,4HGTH ,4HPUMP,4*4H    ,4HNOZZ,4HLE  ,OUTPT028
     D 3*4H    ,4HREDU,4HCTIO,4HN GE,4HAR  ,4H    ,4HFUEL,4*4H    ,     OUTPT029
     E 5*4H    ,4HJET ,4HLIFT,3*4H    ,4HTOTA,4HLS  ,3*4H    /          OUTPT030
      DATA ENGN/4HTF35,2*4H    ,4HTF40,2*4H    ,4HPRCT,4HEUS ,4H1500,   OUTPT031
     A 4HPRAT,4HEUS ,4H1000, 4HTYNE,4H 1A ,4H    ,4HTYNE,4H 1C ,4H    , OUTPT032
     B 4HFT12,4HA   ,4H    ,4HLM15,4H00  ,4H    ,4HLM25,4H00  ,4H    ,  OUTPT033
     C 4HFT4A,4H-2C ,4H    ,4HFT4A,4H-12 ,4H    ,4HFT4C,4H-2  ,4H    /  OUTPT034
      IPRNT=6                                                           OUTPT035
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      WRITE(IPRNT,1)                                                    OUTPT036
    1 FORMAT(5X,49H **** WATERJET PROPULSION SYSTEM OUTPUT DATA ****,///OUTPT037
     A )                                                                OUTPT038
      DO 7 J=ISTRT,NUMB                                                 OUTPT039
      VJRAT(J)=VJ(J)/VO(J)                                              OUTPT040
      VIRAT(J)=VI(J)/VO(J)                                              OUTPT041
      HEADL(J,1)=DELH(J,1)                                              OUTPT042
      HEADL(J,2)=DELH(J,2)-DELH(J,1)                                    OUTPT043
      HEADL(J,3)=DELH(J,3)-HE+RO(2)*XK(2)-DELH(J,2)                     OUTPT044
      HEADL(J,4)=DELH(J,4)-RO(2)*XK(2)-DELH(J,3)                        OUTPT045
      SUM=0.                                                            OUTPT046
      DO 8 I=5,8                                                        OUTPT047
      HEADL(J,I)=DELH(J,I)-DELH(J,I-1)                                  OUTPT048
      IF(I.EQ.8) HEADL(J,8)=DELH(J,8)                                   OUTPT049
    8 SUM=SUM+HEADL(J,I)                                                OUTPT050
    7 HEADL(J,9) =SUM+HEADL(J,1)+HEADL(J,2)+HEADL(J,3)+HEADL(J,4)       OUTPT051
      DRATO=AREA(3)/AREA(2)                                             OUTPT052
      WRITE(IPRNT,3) AIN,DRATO,AJET                                     OUTPT053
    3 FORMAT(27H INLET AREA, TOTAL, FEET**2,F8.2,/,                     OUTPT054
     A 27H STRUT DIFFUSER AREA RATIO ,F8.2,/,                           OUTPT055
     B 25H JET AREA, TOTAL, FEET**2,2X,F8.2,//)                         OUTPT056
      IK=NPUMP+2-NPUMP/2                                                OUTPT057
      XNGT=NGT                                                          OUTPT058
      DO 30 K=ISTRT,NUMB                                                OUTPT059
   30 PC(K)=TDRAG(K)*VO(K)/(550.*SHP(K,NSTG)*XNGT)                      OUTPT060
      WRITE(IPRNT,12)                                                   OUTPT061
   12 FORMAT(24X,3HJET,15X,5HINLET)                                     OUTPT062
      WRITE(IPRNT,11)                                                   OUTPT063
C     IF A EXPLORATORY MOVE IS SUCCESSFUL TRY A PATTERN MOVE IN THAT    OUTPT064
C     DIRECTION. IF ALL EXPLORATORY MOVES ARE UNSUCCESSFUL, DECREASE    OUTPT065
C     STEPSIZE AND RESET THE BASEPOINT.                                 OUTPT066
   11 FORMAT(10H FLOW RATE,5X,3HJET,4X,8HVELOCITY,2X,6H INLET, 2X,      OUTPT067
     A 8HVELOCITY,3X,7HSHP PER,2X,10HPROPULSIVE)                        OUTPT068
      WRITE(IPRNT,13)                                                   OUTPT069
   13 FORMAT(4X,3HCFS,5X,8HVELOCITY,3X,5HRATIO,3X,8HVELOCITY,3X,5HRATIO,OUTPT070
     A 4X,7HTURBINE,2X,11HCOEFFICIENT)                                  OUTPT071
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      WRITE(IPRNT,10) (Q(I),VJ(I),VJRAT(I),VI(I),VIRAT(I),SHP(I,NSTG),  OUTPT072
     A PC(I),(CONDS(J,I),J=1,2),I=ISTRT,NUMB)                            OUTPT073
   10 FORMAT(F9.2,1X,F9.2,1X,F7.2,3X,F9.2,2X,F6.2,4X,F8.0,2X,F9.4,3X,    OUTPT074
     A 2A4)                                                              OUTPT075
      WRITE(IPRNT,16)                                                    OUTPT076
   16 FORMAT(//,5X,6HRADIUS,5X,4HDUCT,5X,5HANGLE)                        OUTPT077
      WRITE(IPRNT,17)                                                    OUTPT078
   17 FORMAT(5X,5HRATIO,5X,6HRADIUS,3X,7HDEGREES,5X,8HLOCATION,4X,5HSHAPOUTPT079
     AE,/)                                                               OUTPT080
      WRITE(IPRNT,18) (XK(I),RO(I),THATA(I),(ELBWS(L,I),L=1,2),(TYPE(L,IOUTPT081
     A ),L=1,3),I=1,IK)                                                  OUTPT082
   18 FORMAT(4X,F4.2,6X,F4.2,5X,F5.2,5X,2A4,4X,3A4)                      OUTPT083
      WRITE(IPRNT,20)                                                    OUTPT084
   20 FORMAT(//)                                                         OUTPT085
      DO 2 K=1,3                                                         OUTPT086
    2 LABEL(K,12)=ENGN(K,IENGN)                                          OUTPT087
      WRITE(IPRNT,27)                                                    OUTPT088
   27 FORMAT(49X,6HCRUISE,3X,3HT/O,6X,10HEVALUATION)                     OUTPT089
      WRITE(IPRNT,28)                                                    OUTPT090
   28 FORMAT(28X,9HSTRUCTURE,3X,5HWATER,5X,4HDUCT,4X,4HDUCT,3X,4HDUCT)   OUTPT091
      WRITE(IPRNT,29)                                                    OUTPT092
   29 FORMAT(29X,7HWEIGHTS,3X,7HWEIGHTS,3X,6HLOSSES,2X,6HLOSSES,6X,      OUTPT093
     A 6HLOSSES)                                                         OUTPT094
      WRITE(IPRNT,44)                                                    OUTPT095
   44 FORMAT(29X,8H(POUNDS),1X,8H(POUNDS),3X,6H(FEET),2X,6H(FEET),6X,    OUTPT096
     A 6H(FEET),/)                                                       OUTPT097
      DO 5 K=1,14                                                        OUTPT098
      LL=K                                                               OUTPT099
      IF(K.GT.7) GO TO 9                                                 OUTPT100
    4 KLL=ISTRT+NUMB-2                                                   OUTPT101
      GO TO (31,32,33,34,35,36),KLL                                      OUTPT102
   31 WRITE(IPRNT,25) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT103
     A J=ISTRT,NUMB)                                                     OUTPT104
   25 FORMAT(1X,5A4,5X,2F10.1,2F8.2)                                     OUTPT105
      GO TO 5                                                            OUTPT106
   32 WRITE(IPRNT,37) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT107
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     A  J=ISTRT,NUMB)                                                   OUTPT108
  37 FORMAT(1X,5A4,5X,2F10.1,2F8.2,8X,F8.2)                             OUTPT109
     GO TO 5                                                            OUTPT110
  33 WRITE(IPRNT,38) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT111
     A  J=ISTRT,NUMB)                                                   OUTPT112
  38 FORMAT(1X,5A4,5X,2F10.1,2F8.2,4X,2F8.2)                            OUTPT113
     GO TO 5                                                            OUTPT114
  34 IF(ISTRT.EQ.1) GO TO 40                                            OUTPT115
     WRITE(IPRNT,39) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT116
     A  J=ISTRT,NUMB)                                                   OUTPT117
  39 FORMAT(1X,5A4,5X,2F10.1,24X,F8.2)                                  OUTPT118
     GO TO 5                                                            OUTPT119
  40 WRITE(IPRNT,41) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT120
     A  J=ISTRT,NUMB)                                                   OUTPT121
  41 FORMAT(1X,5A4,5X,2F10.1,5F8.2)                                     OUTPT122
     GO TO 5                                                            OUTPT123
  35 WRITE(IPRNT,42) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT124
     A  J=ISTRT,NUMB)                                                   OUTPT125
  42 FORMAT(1X,5A4,5X,2F10.1,20X,2F8.2)                                 OUTPT126
     GO TO 5                                                            OUTPT127
  36 WRITE(IPRNT,43) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT128
     A  J=ISTRT,NUMB)                                                   OUTPT129
  43 FORMAT(1X,5A4,5X,2F10.1,16X,3F8.2)                                 OUTPT130
     GO TO 5                                                            OUTPT131
   9 IF(K.EQ.9) LL=8                                                    OUTPT132
     IF(K.EQ.14) LL=9                                                   OUTPT133
     IF(K.EQ.14) WRITE(IPRNT,26)                                        OUTPT134
  26 FORMAT(   26X,60(1H-))                                             OUTPT135
     IF(LL.NE.K) GO TO 4                                                OUTPT136
     WRITE(IPRNT,25) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2)               OUTPT137
   5 CONTINUE                                                           OUTPT138
     WRITE(IPRNT,6)                                                     OUTPT139
     NIMP=XIM                                                           OUTPT140
     WRITE(IPRNT,21)                                                    OUTPT141
  21 FORMAT(15X,9HPUMP DATA,/)                                          OUTPT142
     IF(NSTG.EQ.4) GO TO 48                                             OUTPT143
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      WRITE(IPRNT,45) NIMP                                              OUTPT144
   45 FORMAT(38H AXIAL PUMP WITH INDUCER IMPELLER AND ,I2,17H ADDITIONALOUTPT145
     A STAGE,/)                                                         OUTPT146
      GO TO 49                                                          OUTPT147
   48 WRITE(IPRNT,50) NIMP                                              OUTPT148
   50 FORMAT(23H CENTRIFUGAL PUMP WITH ,I2,34H DOUBLE SUCTION IMPELLERS OUTPT149
     APER PUMP,/)                                                       OUTPT150
   49 WRITE(IPRNT,51)                                                   OUTPT151
   51 FORMAT(5X,4HHEAD,3X,4HNPSH,3X,5HTHOMA,5X,3HRPM,3X,10HEFFICIENCY)  OUTPT152
      WRITE(IPRNT,52) (HPP(I),HSV(I),THOM(I),RPM(I,NSTG),ETAP(I,NSTG),  OUTPT153
     A (CMNDS(J,I),J=1,2), I=ISTRT,NUMB)                                OUTPT154
   52 FORMAT(4X,F6.1,2X,F6.1,3X,F5.3,3X,F6.1,4X,F5.3,5X,2A4)            OUTPT155
      WRITE(IPRNT,53) XNS(NSTG),SM(NSTG),PHI(NSTG),SHI(NSTG),D1S(NSTG), OUTPT156
     A D2S(NSTG),XLP                                                    OUTPT157
   53 FORMAT(/,19H SPECIFIC SPEED,CFS,16(1H.),F7.1,/,                   OUTPT158
     A 27H SUCTION SPECIFIC SPEED,CFS,3(1H.),F7.1,/,                    OUTPT159
     B 17H FLOW COEFFICIENT,18(1H.),F7.3,/,17H HEAD COEFFICIENT,18(1H.),OUTPT160
     C F7.3,/,24H INLET TIP DIAMETER,FEET,11(1H.),F7.2,/,               OUTPT161
     D 23H EXIT TIP DIAMETER,FEET,12(1H.),F7.2,/,                       OUTPT162
     E 17H PUMP LENGTH,FEET,18(1H.),F7.2)                               OUTPT163
      WRITE(IPRNT,57) GERAT(NSTG)                                       OUTPT164
   57 FORMAT(11H GEAR RATIO,24(1H.),F7.2,///)                           OUTPT165
      WRITE(IPRNT,24)                                                   OUTPT166
   24 FORMAT(15X,12HNACELLE DATA,/)                                     OUTPT167
      WRITE(IPRNT,54) DRAT,DM,AI,AIAUX,FLEXT,FLENT                      OUTPT168
   54 FORMAT(21H DIAMETER RATIO,DI/DM,19(1H.),F6.3,/,                   OUTPT169
     A 25H MAXIMUM DIAMETER,DM,FEET,15(1H.),F6.2,/,                     OUTPT170
     B 29H INLET AREA PER NACELLE,FT**2,11(1H.),F6.2,/,                 OUTPT171
     C 39H AUXILIARY INLET AREA PER NACELLE,FT**2,F7.2,/,               OUTPT172
     D 21H FOREBODY LENGTH,FEET,19(1H.),F6.2,/,                         OUTPT173
     E 16H LIP LENGTH,FEET,24(1H.),F6.2)                                OUTPT174
      WRITE(IPRNT,55) ELDIF,ELN                                         OUTPT175
   55 FORMAT(21H DIFFUSER LENGTH,FEET,19(1H.),F6.2,/,                   OUTPT176
     A 20H NACELLE LENGTH,FEET,20(1H.),F6.2,//)                         OUTPT177
      TEM=TC*CEM                                                        OUTPT178
      WRITE(IPRNT,47) TC,T,C,T1,C1,TEM,CEM                              OUTPT179
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47 FORMAT(10X,19HSTRUT CONFIGURATION,//,                         OUTPT180
  A 3X,3HT/C,5X,9HTHICKNESS,5X,5HCHORD,/,                        OUTPT181
  B 1X,F5.3,7X,F4.1,8X,F4.1,5X,4HROOT,/,                         OUTPT182
  C 13X,F4.1,8X,F4.1,5X,3HTIP,/,                                 OUTPT183
  D 13X,F4.1,8X,F4.1,5X,9HWATERLINE,/)                           OUTPT184
    WRITE(IPRNT,56) (TDRAC(I),RDD(I),STRTD(I),SPRAY(I),          OUTPT185
  A (CONDS(J,I),J=1,2),I=ISTRT,NUMR)                             OUTPT186
56 FORMAT(10X,14HDRAG ESTIMATES,/,4X,5HTOTAL,5X,7HNACELLE,5X,5HSTRUT,OUTPT187
  A 5X,5HSPRAY,/,(1X,F8.1,5X,F7.1,4X,F6.1,4X,F6.1,5X,2A4))       OUTPT188
    WTRAT=(WGTS(1,14)+WGTS(2,14))/DISP                           OUTPT189
    WRITE(IPRNT,23) WTRAT                                        OUTPT190
23 FORMAT(/,30H TOTAL SYSTEM WEIGHT RATIO IS ,F6.4)              OUTPT191
    WRATE=(WGTS(1,14)+WGTS(2,14)-WGTS(2,11))/DISP                OUTPT192
    WRITE(IPRNT,46) WRATE                                        OUTPT193
46 FORMAT(/,37H SYSTEM WEIGHT RATIO WITHOUT FUEL IS ,F6.4)       OUTPT194
    WRITE(IPRNT,6)                                               OUTPT195
 6 FORMAT(1H1)                                                   OUTPT196
    RETURN                                                       OUTPT197
    END                                                          OUTPT198
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```
      BLOCK DATA                                                        BLKDT000
      COMMON /PARMS/ VJVO,VIVO,DIDM                                     BLKDT001
      COMMON /STRTC/TC,T,C,T1,C1,CFM                                    BLKDT002
      COMMON /PUMM/QQ(5),D1S(5),D2S(5),XNS(5),SM(5),PLP(5),NSTG,SHI(5), BLKDT003
     A XIM                                                              BLKDT004
      COMMON /H2O/TEMP,PV,RHOW,GNU,HA                                   BLKDT005
      COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPF,XLP               BLKDT006
      COMMON /CONST/PI,G,RHCD                                           BLKDT007
      COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ           BLKDT008
      COMMON /FLPW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)           BLKDT009
      COMMON /TOLER/DELTA                                               BLKDT010
      COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)                   BLKDT011
      COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)      BLKDT012
      COMMON /NACLL/DRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN        BLKDT013
      COMMON /INDEX/IEVAL,IFOPT,ISTRT,NUMB,IENGN,ITYPE,ICOMP,NPUMP,NGT  BLKDT014
      COMMON /ITABL/L(2)                                                BLKDT015
      DATA TEMP/59./                                                    BLKDT016
      DATA HS,HE,HCL,XLS,XLPE,XLP/5.,10.,2.,20.,2.,0./                  BLKDT017
      DATA PI,G,RHCD/3.14159,32.174,14.92/                              BLKDT018
C     ENGINE PERFORMANCE DATA                                           BLKDT019
      DATA PERF/2220.,2840.,.59,14500.,1050.,2850.,3060.,.55,14500.,    BLKDT020
     11050.,2800.,3510.,.63,1500.,3200.,2800.,3510.,.63,1000.,3300.,    BLKDT021
     23320.,4250.,.49,3110.,2900.,4160.,5300.,.47,3110.,2300.,          BLKDT022
     32220.,2840.,.79,9000.,1010.,12500.,14000.,.575,5500.,7500.,       BLKDT023
     422200.,22500.,.41,3400.,10500.,19150.,24200.,.52,3600.,14200.,    BLKDT024
     521750.,26950.,.52,3600.,14200.,27600.,34400.,.48,3600.,14200./    BLKDT025
      DATA WGTS,CGS,DELH/165*0./                                        BLKDT026
      DATA DRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN/9*1./           BLKDT027
      DATA RO/4*1./,XIM/1./                                             BLKDT028
      DATA TC,T,C,T1,C1,CFM/6*1./                                       BLKDT029
      DATA THATA,XK/3*90.,30.,3*1.5,2./                                 BLKDT030
      DATA SHP/25*1000./,DELTA/.05/                                     BLKDT031
      DATA VJVO,VIVO,DIDM/1.8,.7,.7/                                    BLKDT032
      DATA Q,VJ,VI,AREA/15*0.,11*1./                                    BLKDT033
      DATA IFOPT,IENGN,IEVAL/0,8,0/                                     BLKDT034
      DATA L/11,1/                                                      BLKDT035
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      DATA TYPE/12**H     /                                           BLKDT036
      DATA NSTG/1/                                                    BLKDT037
      END                                                             BLKDT038
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Thesis 134721
G442 Gill
Design optimization
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